Apidologie

Pests, pathogens, and parasites of honey bees in Asia

--Manuscript Draft--

Manuscript Number:	APID-D-15-00082R2
Full Title:	Pests, pathogens, and parasites of honey bees in Asia
Article Type:	Review Article
Keywords:	Asia; Bee virus; Tropilaelaps; Asian bee mites; honey bees; pathogen
Corresponding Author:	Panuwan Chantawannakul, PhD Chiang Mai University A. Meung, Chiang Mai THAILAND
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Chiang Mai University
Corresponding Author's Secondary Institution:	
First Author:	Panuwan Chantawannakul, PhD
First Author Secondary Information:	
Order of Authors:	Panuwan Chantawannakul, PhD
	Lilia I de Guzman, PhD
	Jilian Li, PhD
	Geoffrey R. Williams, PhD
Order of Authors Secondary Information:	
Funding Information:	Thailand Research Fund (TH) — Dr Panuwan Chantawannakul
	National Research Council of Thailand (TH) — Dr Panuwan Chantawannakul
	Chiang Mai University (TH) — Dr Panuwan Chantawannakul
Abstract:	Asia is home to at least nine honey bee species, including the introduced Apis mellifera. In addition to A. mellifera and Apis cerana being widely employed for commerical beekeeping, the remaining non-managed species also have important ecological and economic roles on the continent. Species distributions of most honey bee species overlap in Southeast Asia. This promotes the potential for interspecific transmission of pests and parasites, and their spread to other parts of the world by human translocation. The decline of honey bee populations is of great concern around the world, including in Asia. The global colony losses of A. mellifera are believed to be caused, in part, by pests, pathogens and parasites originating from Asia, such as the mite Varroa destructor, the microsporidian Nosema ceranae, and some bee viruses. This review discusses important pests, pathogens and parasites in both the introduced A. mellifera and native honey bees in Asia to provide an overall picture of honey bee health in the region and future threats to the apiculture industry.
Response to Reviewers:	Dear Editor, All minor comments have been edited except: - line 364 & 383 , we have re checked the original article and the authors refer to 'Apis indica'. Therefore, we did not change the species name to 'A. cerana'. We have shorten the section 2 and 3 regarding to the editor 's suggestion. With my best regards Panuwan Chantawannakul

October 7th, 2015

Dear Editor,

Attached is the manuscript entitled "**Pests, pathogens, and parasites of honey bees in Asia"** This is a revised manuscript APID-D-15-00082R1, and in this version, the manuscript has been edited regarding to all your comments and suggestions. We have shorten the Section 2 &3 and the length of current version is 81,010 characters including 228 references. We also changed the previous title (Parasites and pests of honey bee in Asia) to cover all parts of our review. We hope that our review would benefit the readers of Apidologie (special issue) especially ones who are interested to gain bee health information in Asia.

We are looking forward to hearing from you. Thank you very much for handling our manuscript.

Sincerely yours,

Assoc. Prof. Dr. Panuwan Chantawannakul

Corresponding author

Pests, pathogens, and parasites of honey bees in Asia

Panuwan Chantawannakul[1*], Lilia I. de Guzman[2], Jilian Li[3], Geoffrey R. Williams[4, 5]

[1]Bee Protection laboratory (BeeP), Department of Biology, Faculty of Science, Chiang Mai University, 50200 Thailand

[2]USDA-ARS, Honey Bee Breeding, Genetics and Physiology Laboratory, Baton Rouge, Louisiana, 70820 USA

[3]Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, Beijing, 100093 China

[4]Institute of Bee Health, Vetsuisse Faculty, University of Bern, Bern, 3003 Switzerland

[5]Agroscope, Swiss Bee Research Centre, Bern, 3003 Switzerland

*Corresponding author: panuwan@gmail.com

Abstract – Asia is home to at least nine honey bee species, including the introduced *Apis mellifera*. In addition to *A. mellifera* and *Apis cerana* being widely employed for commerical beekeeping, the remaining non-managed species also have important ecological and economic roles on the continent. Species distributions of most honey bee species overlap in Southeast Asia. This promotes the potential for interspecific transmission of pests and parasites, and their spread to other parts of the world by human translocation. The decline of honey bee populations is of great concern around the world, including in Asia. The global colony losses of *A. mellifera* are believed to be caused, in part, by pests, pathogens and parasites originating from Asia, such as the mite *Varroa destructor*, the microsporidian *Nosema ceranae*, and some bee viruses. This review discusses important pests, pathogens and parasites in both the introduced *A. mellifera* and native honey bees in Asia to provide an overall picture of honey bee health in the region and future threats to the apiculture industry.

Keywords: Asia/ Bee virus/ Tropilaelaps / Asian bee mites/ honey bees/ pathogen

1. INTRODUCTION

The natural world is ripe with examples of species population dynamics driven by the biotic environmental pressures such as parasites, predators, and pests. Honey bees (*Apis* spp.) are no exception (Ellis and Munn 2005). In recent years both wild and managed honey bees have experienced dramatic reductions in numbers in various regions of the world (Neumann and Carreck 2010), which has led to a flurry of research into explanations for these observations. The vast majority of these efforts have focused on the western honey bee (*Apis mellifera*), which is unquestionably the single most globally ubiquitous and economically important honey bee species (Crane 1999). The general consensus is that reductions in *A. mellifera* colony numbers are primarily the consequences of multiple concomitant environmental pressures, of which parasites and pests play an important role (e.g. vanEngelsdorp and Meixner 2010; Williams et al. 2010; Neumann and Carreck 2010). Relative to *A. mellifera*, investigations into the health of other honey bee species has taken a backseat, despite their importance to economic and social systems around the world (Crane 1999).

In this review we focus on parasites and pests of honey bees in Asia. The region hosts multiple species of native honey bees, as well as the introduced *A. mellifera*. Despite the importance of these species as a source of bee products and pollination services (Oldroyd and Wongsiri 2006; Sanpa et al. 2015; Pattamayutanon et al. *in press*), the health of native Asian honey bees has been relatively less studied compared to that of *A. mellifera*. Furthermore, comparative insights into parasites and pests of *A. mellifera* with native species in Asia provides powerful insights into parasite-host responses among these organisms. This is particularly important because several devastating parasites have host-jumped from native Asian honey bees to *A. mellifera* to become of global concern (Rosenkranz et al. 2010; Fries 2010). First, we introduce honey bee species diversity in the region as well as the interactions of these species with human. We then review pest, pathogen, and parasite interactions with

honey bees in Asia, and conclude by providing directions for further investigations that would promote honey bee health in both Asia and abroad.

2. *APIS* SPECIES DIVERSITY

Asia hosts at least eight native honey bee species, with diversity highest in the tropics (Crane 1999). Multi-comb-making cavity-nesting species, *Apis cerana*, *Apis koschevnikovi*, *Apis nigrocincta*, and *Apis nuluensis* are particularly ubiquitious as a group and are classified as medium-sized bees (Ruttner 1988; Otis 1996; Tingek et al. 1996; Hepburn et al. 2001; Radloff et al. 2005a; Radloff et al. 2005b; Hepburn and Hepburn 2006; Takahashi et al. 2007; Tan et al. 2008; Radloff et al. 2010). Residing in protective cavities such as tree hollows, they are also well-known to nest in human-made structures throughout the region (Oldroyd and Wongsiri 2006). Single-comb-making open- air- nesting honey bees include the dwarf (*Apis florea* and *Apis andreniformis*) and giant (*Apis dorsata* and *Apis laboriosa*) honey bees (Sakagami et al. 1980; Otis 1996; Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011). This group is limited to sub-tropical and tropical areas likely due to inherent vulnerability to the elements as a result of their open-nesting habits (Hepburn et al. 2005; Hepburn and Hepburn 2005; Oldroyd and Wongsiri 2006). These species can be found nesting on branches, cliff faces, and even under outcroppings of large urban structures (Crane 2003). Most recently, two new species *Apis indica* in southern India and *Apis breviligula* in the Philippines have been proposed (Lo et al. 2010). They were previously included with *A. cerana* and *A. dorsata*, respectively. In addition to native species, the introduced *A. mellifera* is widespread throughout the region (Wongsiri and Tangkanasing 1987; Crane 1999; Oldroyd and Wongsiri 2006).

3. INTERACTIONS WITH HUMANS

Asians have been associated with honey bees for thousands of years for food, medicinal products, and trade (Crane 1999). Opportunistic honey bee hunting preceded ownership of wild nests by individuals or communities (Oldroyd and Wongsiri 2006). The earliest evidence of annual claims to *A. dorsata* nests occur on rock faces (e.g China between 265 and 290) (Crane 1999). Managing honey bees in hives first developed using *A. cerana*, whereby hives were fashioned using hollow logs, clay pots, or straw baskets. In western Asian countries like Pakistan and Afghanistan, this management technique occurred as early as 300 BC. In the east, hive beekeeping began in China circa 200. Adoption of beekeeping in other countries was sporadic in history, with Malaysia being one of the last countries to adopt native honey bee hive beekeeping in 1936 (Crane 1999). More recently, large scale commercial hive beekeeping using *A. cerana* have been developed in temperate areas of China and India (Fig. 1A&B). The *A. cerana* subspecies native to these areas are more profitable because they are less likely to abscond than other subspecies found in sub-tropical and tropical regions (Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011). Nevertheless, due to its relatively greater potential for profitability compared to *A. cerana*, *A. mellifera* was widely imported from Europe, North America, and Oceania starting first in Russia, east of the Urals in the late 1700s, followed by Japan, India, and Indonesia in the late 1800s. By the 1980s, nearly every country in Asia accommodated the introduced *A. mellifera* (Crane 1999; Wu et al. 2006; Arai et al. 2012; Sanpa and Chantawannakul 2009). Asia currently accommodates the largest number of managed *A. mellifera* honey bee colonies in the world (FAO 2014). Organized surveys of *A. mellifera* populations in Asia report lower losses of managed colonies compared to Europe and North America (van der Zee et al. 2012). However, few work has focused on populations of native species, particularly because their migratory nature makes their study difficult. Anecdotal reports suggest *A. cerana* in China is under severe pressure from habitat

and forage plant losses, displacement by the introduced *A. mellifera*, as well as inter-specific transfer of pathogens and parasites (Yang 2005; He and Liu 2011; Li et al. 2012).

4. HEALTH STRESSORS

4.1 Mites

Asian honey bees are indigenous hosts of several species of parasitic mites. The sympatric existence of different species of honey bees and their associated parasitic mites in Asia potentially promotes the exchange of parasites among them, as well as concurrent infestations by multiple mite species at the colony or individual levels (Anderson 1994; Anderson and Trueman 2000; Buawangpong et al. 2015).

Varroa spp.

Within the genus *Varroa*, four mite species are described, *Varroa jacobsoni* (Oudemans 1904), *Varroa underwoodi* (Delfinado-Baker and Aggarwal 1987), *Varroa rindereri* (de Guzman and Delfinado-Baker 1996), and *Varroa destructor* (Anderson and Trueman 2000), all of which are known parasites of honey bees. First identified was *V. jacobsoni* parasitizing *A. cerana* in Java (Oudemans 1904). However, subsequent investigations in the region described additional species. *V. underwoodi* and *V. rindereri* were observed parasitizing *A. cerana* in Nepal and *A. koschevnikovi* in Borneo, respectively (Delfinado-Baker and Aggarwal 1987; de Guzman and Delfinado-Baker 1996). Revaluation of *V. jacobsoni* revealed an additional species, *V. destructor*, infecting *A. mellifera* (Anderson and Trueman 2000). This redescription sent shock-waves throughout Asia and abroad, as it became apparent that *V. destructor*, rather than *V. jacobsoni*, was the most prevalent *Varroa* mite parasitizing honey bees around the world.

Varroa species nearly ubiquitiously parasitize honey bees throughout Asia (Fig. 2).

All species successfully parasitize cavity-nesting honey bees. *V. jacobsoni* infests five honey bee species, including *A. cerana*, *A. koschevnikovi*, *A. mellifera*, *A. nigrocincta*, and *A. nuluensis* (Woyke et al. 1987a; Delfinado-Baker et al. 1989; Koeniger et al. 2002; Otis and Kralj 2001; de Guzman et al. 1996). In contrast, *V. destructor* has only been recorded in *A. cerana* and *A. mellifera* colonies (Anderson and Trueman 2000). *V. underwoodi* is restricted to *A. cerana*, *A. nigrocincta* and *A. nuluensis*. Unlike its congeners, *V. rindereri* appears to be a species-specific parasite. It was found successfully infesting *A. koschevnikovi*, but was collected from debris of *A. dorsata* in Borneo along with *V. jacobsoni* (Koeniger et al. 2002).

The general morphology and chaetotaxy of the four *Varroa* species are similar. However, several characters such as body size (Table 1) and shape, peritreme size, and length and number of marginal setae can be used to distinguish them. A wide genetic variation within and between *V. jacobsoni* and *V. destructor* populations exists in Asia, and may play an important role in the pathogenicity of these parasites. Currently twenty-four haplogroups, fifteen for *V. jacobsoni* and nine for *V. destructor*, are recognized (de Guzman and Rinderer 1998, 1999; de Guzman et al. 1997, 1998, 1999; Anderson and Trueman 2000; Fuchs et al. 2000; Zhou et al. 2004; Solignac et al. 2005; Warrit et al. 2006; Navajas et al. 2010), with the Korean (K) and Japanese (J) haplotypes of *V. destructor* being the most successful parasites of *A. mellifera* (Rosenkranze et al. 2010). Of these, the K haplotype is competitively superior to J, and represents the most pathogenic *Varroa* mite haplotype in Asia and abroad. Virulent parasites are generally more competitive than less virulent ones, and may possibly displace them (Navajas et al. 2010). Failure to detect J haplotype mites in Thailand that were reported earlier (de Guzman and Rinderer 1999; Anderson and Trueman 2000; Navajas et al. 2010) may be a result of such a displacement event and not an erroneous finding as suggested by Warrit et al. (2006). Recent genetic analysis of *Varroa* mites in Asia revealed new invasions and hybridization between haplogroups (Navajas et al. 2010). The virulence of hybrid mites to honey bees has yet to be established.

159 In the Philippines, the Papua New Guinea (=Java) *V. jacobsoni* haplotype parasitizes
160 *A. cerana* (de Guzman and Rinderer 1999), and three unresolved *V. destructor* haplotypes are
161 known to reproduce in *A. cerana* drone brood (Anderson 2004). In *A. mellifera* and *A. cerana*,
162 *V. jacobsoni* reproduces in drone brood only (Anderson 1994; Anderson and Sukarsih 1996;
163 Anderson and Fuchs 1998), whereas reproduction of *V. destructor* in *A. cerana* is likely
164 dependent on their haplotype or strain of the host bees (de Jong 1988). Inability of *V.*
165 *jacobsoni* to reproduce in worker brood of *A. cerana* and *A. mellifera* has most likely limited
166 its distribution and impact as drone brood is seasonally produced and relatively less crucial to
167 overall colony functioning (de Guzman and Rinderer 1999). Variations in mite infestation or
168 reproduction may be attributed to the combined effects of bee behavior, species and
169 haplogroup of mites. While grooming behavior removes mites from adult bees (Rinderer et al.
170 2010), hygienic behavior disrupts mite reproductive output when mites and infested
171 developing bees are removed from brood cells (Kirrane et al. 2011). *A. cerana* is particularly
172 well known for such behaviors (Peng et al. 1987a, 1987b).
173 Although *A. cerana* is the indigenous host of *V. jacobsoni* and *V. destructor*, much of
174 the life histories of the two are based on data using *A. mellifera* as the host. No biological
175 observations are available for either *V. rindereri* and *V. underwoodi*. In *A. mellifera*, *V.*
176 *destructor* reproduces in both worker and drone brood (Anderson and Trueman 2000;
177 Rosenkranz et al. 2010). Female *Varroa* mites enter brood cells before capping, with total
178 developmental time about six days (Ifantidis 1990). One female can produce an average of 1.8
179 and 3 mature daughters in worker and drone brood cells, respectively (Donzé et al. 1996).
180 Mating occurs within the capped brood cell; young mated adults subsequently leave the cell
181 with the emerging bee. Phoresy is a very important phase on the survival, dispersal, and even
182 reproductive success of *Varroa* mites. The phoretic stage lasts from 4 days to a few months,
183 depending on availability of brood (Martin 1998; Beetsma et al. 1999). While phoretic, mites

can feed on adult bees through soft membranes such as those between abdominal tergites (De D'Aubeterre et al. 1999).

Similar to other regions of the world, parasitism by *Varroa* can have devastating consequences for honey bees such as reduced longevity, immunosuppression, and increased viral prevalence and intensity (Rosenkranz et al. 2010). However, pathogenicity is largely specific to the particular mite and honey bee species considered, with natural parasite-host associations typically less pathogenic. In *A. mellifera*, bee parasitic mite syndrome is a disease complex of colonies simultaneously infested with *V. destructor* mites and infected with viruses (Shimanuki et al. 1994). Detection of bee viruses in *Varroa* mites suggests that mites are potential vectors that facilitate the horizontal transmission of bee viruses among honey bees (Chen and Siede 2007). The co-existence of several bee viruses (Kashmir bee virus (KBV), Acute bee paralysis virus (ABPV), Deformed wing virus (DWV), Sacbrood virus (SBV), and Black queen cell virus (BQCV)) in a single mite suggests that *V. destructor* can be responsible for multiple infections by viruses in apiaries in Thailand (Chantawannakul et al. 2006). This combination of mite infestation and viruses likely aggravates the health of colonies.

Tropilaelaps spp.

Four species of *Tropilaelaps* have been described in the mite family Laelapidae. First identified, *Tropilaelaps clareae* was collected from dead *A. mellifera* bees and field rats near beehives in the Philippines (Delfinado and Baker 1961). Twenty years later, *Tropilaelaps koenigerum* was observed parasitizing *A. dorsata* in Sri Lanka (Delfinado-Baker and Baker 1982). More recently, Anderson and Morgan (2007) described two species, *Tropilaelaps mercedesae* and *Tropilaelaps thaii* parasitizing *A. dorsata* and *A. mellifera* in mainland Asia and *A. laboriosa* in the Himalayas, respectively. Similar to the reclassification of *V. jacobsoni*

and *V. destructor* (Anderson and Trueman 2000), *T. mercedesae* was initially described as *T. clareae* (Anderson and Morgan 2007).

Tropilaelaps mites are believed to be indigenous parasites of the giant honey bees, *A. dorsata*, *A. laboriosa*, and *A. breviligula* (Laigo and Morse 1968; Delfinado-Baker et al. 1985; Anderson and Morgan 2007). Since its discovery, all reports on *Tropilaelaps* are from the distribution range of the giant honey bees, and therefore suggest co-evolution (Anderson and Morgan 2007). *T. clareae* was first observed infesting *A. mellifera* in the Philippines, and recently found parasitizing *A. breviligula* in the Philippines and Sulawesi Island in Indonesia (Anderson and Morgan 2007). Reclassification of *T. mercedesae* by Anderson and Morgan (2007) suggests that the mite parasitizes *A. dorsata* and *A. mellifera* throughout southern mainland Asia and Indonesia, apart from Sulawesi Island, as well as *A. laboriosa* in the Himalayas (Fig 3). Earlier studies classifying *T. mercedesae* as *T. clareae* (Delfinado-Baker 1982; Kapil and Aggarwal, 1987; Delfinado-Baker et al. 1989; Wongsiri et al. 1989; Abrol and Putatunda 1995; Koeniger et al. 2002) need to be re-examined. *T. koenigerum* is a parasite of *A. dorsata* in Sri Lanka, mainland Asia, and Indonesia apart from Sulwasesi and Borneo (Delfinado-Baker and Baker 1982; Anderson and Morgan 2007), and is known to co-infest *A. dorsata* colonies in Borneo and Thailand with *T. mercedesae* (Delfinado-Baker et al. 1989; Koeniger et al. 2002). Reproduction by *T. koenigerum* on *A. cerana* brood was observed in India (Abrol and Putatunda 1995) and by one adult *T. mercedesae* in Thailand (Anderson and Morgan 2007). *T. koenigerum* has only been observed in *A. mellifera* debris in Thailand (Kavinseksan, per. com.). Conversely, *T. thaii* has only been observed parasitizing *A. laboriosa* in Vietnam (Anderson and Morgan 2007).

Molecular and morphological techniques can be used to identify *Tropilaelaps* and to study their evolutionary history (Anderson and Morgan 2007). Morphologically, several characters are used to distinguish them, including body size, apex of the epigynial plate, anal plate shape, structure of the apical tooth of the chelicerae, and configuration of the apex of

male spermatodactyl. *T. mercedesae* is larger than *T. clareae* or *T. thaii*, with *T. koenigerum* the smallest (Table 1). Molecularly, the most comprehensive survey of *Tropilaelaps* mites to date by Anderson and Morgan (2007) using multiple gene sequences revealed that of 89 widespread isolates, 46 haplotypes fell into 4 lineages that can each be considered a separate species. Genetic differences within species were also identified, but require further investigation to better understand their intra-species phylogenetic relationships.

Much of the life cycle of *Tropilaelaps* is based on *T. mercedesae* infesting *A. mellifera* colonies during a period when it was previously classified as *T. clareae.* Hence, re-examinations are warranted. Like *Varroa* or *Euvarroa*, *Tropilaelaps* also enters brood cells before they are sealed to complete their life cycle (Sammataro 2011). Foundress mites start to lay eggs shortly before the brood cell is capped, which allows nearly all progeny to reach adulthood before the adult bee emerges (Ritter and Schneider-Ritter 1988). The development time for mites is estimated to be approximately 6 and 8.7 days *in vivo* (Woyke 1987c) and *in vitro*, respectively (Kitprasert 1984), and a single foundress can produce up to four progeny (Woyke 1987b). Unlike *Varroa* and *Euvarroa* in its indigenous host, *A. dorsata*, *Tropilaelaps* appear to not show a gender preference between worker and drone brood (Koeniger et al. 2002; Buawangpong et al. 2013). The phoretic period of *Tropilaelaps* is short, surviving approximately 1-3 days on adult bees *in vitro* (Kitprasert 1984; Woyke 1984; Koeniger and Musaffar 1988; Rinderer et al. 1994). As a result, rapid oviposition, reduced life cycle period, and reproduction in both worker and drone brood cells, contribute to relatively higher populations of *Tropilaelaps* in colonies compared to *Varroa* or *Euvarroa* (Buwangpong et al. 2015). When both *T. mercedesae* and *V. destructor* are experimentally introduced into an individual brood cell of *A. mellifera*, normal reproduction of both mites was observed (Buwangpong et al. 2015). Natural co-infestation of *Varroa* and *Tropilaelaps* does occur in *A. mellifera* brood; however, this is rare (<0.1 %) (Buwangpong et al. 2015). Additionally, *T.*

koenigerum and *T. mercedesae* have been found infesting the same *A. dorsata* colony, but not the same brood cell (Delfinado-Baker et al. 1989; Koeniger et al. 2002).

Like *Varroa* and *Euvarroa*, pathogenicity of *Tropilaelaps* is believed to be closely tied to specific parasite-host associations. Few studies have evaluated the effects of these mites on honey bees, particularly their native hosts. Anecdotal reports suggest *T. mercedesae* and *T. clareae* severely affect *A. mellifera* throughout the region whereas *T. koenigerum* and *T. thaii* are believed to be harmless to *A. mellifera* (Burgett et al. 1983; Anderson and Morgan 2007). By using artificial mite-inoculation in *A. mellifera* brood, the proportion of non-reproductive *T. mercedesae* was found to be lower than that of *V. destructor*. Both mites produced similar numbers of progeny. In natural infestations of *A. mellifera* in Thailand, the average worker brood infestations of *T. mercedesae* (19.9 %) were significantly higher than that of *V. destructor* (0.7 %). This higher prevalence and reproductive ability of *T. mercedesae* in concurrently infested colonies reaffirm the competitive advantage of *T. mercedesae* over *V. destructo*r, and their reported negative impact to *A. mellifera* colonies (Buawangpong et al. 2015). Additionally, *T. mercedesae*-inoculated *A. mellifera* pupae showed higher levels and incidence of DWV compared to uninfested pupae (Khongphinitbunjong et al. 2015). The mite has been shown to promote wing deformation and reduce bee longevity in Thailand (Khongphinitbunjong et al., submitted). Both surveys in China and Thailand suggest the mite can vector DWV (Dainat et al. 2008; Forsgren et al. 2009; Khongphinitbunjong et al. 2015). However, no other bee viruses could be found in *T. mercedesae* and suggest that the major impact of mite infestation is caused by the mite itself (Khongphinitbunjong et al. 2015).

In contrary, *Tropilaelaps* populations are generally found to be low in their natural giant honey bee hosts (Buawangpong et al. 2013). Likely the result of parasite-host co-evolution, *A. dorsata* exhibits a high grooming behavior against *T. mercedesae* when compared to *A. mellifera* (Büchler et al. 1992; Koeniger et al. 2002; Khongphinitbunjong et al. 2012). Under artificial mite inoculation, *A. mellifera* removed brood infested with *T.*

mercedesae (52.6%) and peaked during the second and third days post inoculation (Khongphinitbunjong et al. 2014). Information on hygienic behavior of giant honey bee against *Tropilaelaps* is not available. However, frequent absconding, possibly triggered by high mite infestation, or migration away from the nest, may also play important roles in the suppression of *Tropilaelaps* populations (Koeniger et al. 2002), as would its inability to feed on adult bees (Kitprasert 1984; Woyke 1984; Koeniger and Musaffar 1988; Rinderer et al. 1994; Kavinseksan et al. 2003).

Control of *Varroa* and *Tropilaelaps* mites

Numerous strategies for managing economically important mites of honey bees exist, including the use of chemotherapy, physical, and cultural methods (Sammataro 2011). When unmanaged, *Varroa* and *Tropilaelaps* are responsible for the rapid decline in colony health of *A. mellifera* colonies in Asia (Wongsiri and Tangkanasing 1987; Buawangpong et al. 2015). Although all Asian honey bees have mites associated with them, only *A. mellifera* colonies are managed for mite control because of the relative ease of their management and because the severe economic penalties this species faces when mites are not controlled (Wongsiri and Tangkanasing 1987). Many acaricides used for *V. destructor* control also likely work for *Tropilaelaps* (Sammataro 2011), including tau-fluvalinate, amitraz, formic acid, and thymol for *T. clareae* on *A. mellifera* in Thailand (Wongsiri and Tangkanasing 1987; Burgett and Kitprasert 1990), Vietnam (Woyke 1987a), and Pakistan (Raffique 2012), respectively. Currently the use of fluvalinate and coumaphos is widespread throughout the region (Wongsiri and Tangkanasing 1987; Akratanakul 1990). Due to the apparent short lifespan of *Tropilaelaps* on adult bees, interrupting brood rearing by queen caging or by removing all brood from colonies are effective to control *T. mercedesae* in Pakistan (Woyke 1984, 1985). Furthermore, leaves of alagaw (*Premna odorata*) and lemon grass (*Andropogon citratus*) are used to manage both mites with mixed success in the Philippines (Cervancia 1993; Booppha

et al. 2010). Breeding for *Varroa* or *Tropilaelaps* resistance has not gained much popularity among Asian countries.

Euvarroa spp.

To date, two species from the genus *Euvarroa* are believed to be associated with five honey bee species in Asia: the open- air nesters *A. andreniformis*, *A. florea*, *A. dorsata*, as well as the cavity- nesters *A. cerana* and *A. mellifera*. *Euvarroa sinhai* was first observed from *A. florea* samples collected in 1971 in India (Delfinado and Baker 1974) and *E. wongsirii* was first observed in *A. andreniformis* in Thailand (Lekprayoon and Tangkanasing 1991). These two *Eurvarroa* species can be easily distinguished by the shape of their body and number of marginal setae. *E. sinhai* is pear-shaped with 39-40 marginal setae whereas *E. wongsirii* is triangular or wider posteriorly with 47-54 long setae (Delfinado and Baker1974; Lekprayoon and Tangkanasing 1991).

Infestations by *E. wongsirii* have only been reported in *A. andreniformis* in Thailand and Malaysia (Lekprayoon and Tangkanasing 1991). *E. sinhai* has been reported in *A. florea* in India, Iran, Sri Lanka and Thailand (Delfinado and Baker 1974; Koeniger et al. 1983; Mossadegh 1991) and *A. andreniformis* in Thailand (Delfinado-Baker et al. 1989), *E. wongsirii* has not been observed in *A. florea* nests. Nevertheless, both mites have been collected from hive debris, with *E. sinhai* from *A. mellifera* colonies in India and Thailand (Kapil and Aggarwal 1987; Lekprayoon and Tangkanasing 1991), and *E. wongsirii* from *A. dorsata* in Borneo (Koeniger et al. 2002) (Fig. 4). *Euvarroa* infestations are generally low in honey bee colonies, with decreased infestation likely due to host hygienic behavior of dwarf honey bee workers removing dead brood together with their infesting mites (Kitprasert 1995). Limited food supply of the single comb open air nesters, as well as reduced brood cell diameter of dwarf honey bees, may also contribute to suppressed mite populations (Rinderer et al. 1996). Drone reproduction is also seasonal and swarming further reduces *Euvarroa*

populations within colonies by disrupting bee brood, and hence mite reproduction (Kitprasert 1995).

Compared to *Varroa* the life history of *Euvarroa* is not well studied. The limited biological information available is based on observations of *E. sinhai* only, but the life history of the species appears to be similar to that of *Varroa* by parasitizing brood (Sammataro 2011). *In vitro* study using *A. mellifera* worker brood determined that the life cycle of *E. sinhai* is 5 days for males and 6-7 days for females, which can produce 4.3 progeny per infested *A. mellifera* (Mossadegh 1990). *E. sinhai* also prefers adult *A. florea* drones over workers (Akratanakul 1975; Mossadegh 1991; Kitprasert 1995). In some cases, a single brood cell can have up to 15 mites (Akratanakul 1975), which may lead to death of of the drone brood (Kitprasert 1995). It appears that average reproduction of a foundress mite is higher in queenless (3.6 progeny/host) than in queenright (3.3 mites/host) colonies, with seven maximum progeny (Kitprasert 1995). Post-emergence, the mite can survive on adult workers for 4 to 10.5 months during broodless periods (Mossadegh 1990). In the laboratory, *E. sinhai* displayed higher survival on adult *A. mellifera* workers compared to *A. cerana* (Koeniger et al. 1993).

Acarapis spp.

Three species of mites are known from the genus *Acarapis*; all are parasites of adult honey bees. First classified was *Acarapis woodi* in the early 1900s in England's Isle of Wight (Rennie 1921), followed by *Acarapis dorsalis* and *Acarapis externus* on several continents (Morgenthaler 1934). All three species parasitize honey bees in Asia.

The distribution of the three *Acarapis* species in Asia is not well established. The first report of *A. woodi* parasitizing honey bees in the region came from India (Michael 1957; Milne 1957). The species has since been observed parasitizing *A. mellifera* in Egypt, Iran,

Israel, Jordan, Kuwait, Lebanon, Palestine and Syria (Matheson 1993; Rashad et al. 1985; Gerson et al. 1994; Mossadegh and Bahreini 1994; Amr et al. 1998; OIE 2004), and *A. indica* in India, Pakistan, Bangladesh, and China (Delfinado and Baker 1982). Recently, *A. woodi* was observed in dead bees from collapsing colonies of *A. cerana japonica* in Japan (Kojima et al. 2011). It was also detected in Bhutan, Nepal, Hong Kong and Thailand; however, the honey bee host was not identified (Matheson 1993; Matheson 1995). Only in Iran has *A. dorsalis* and *A. externus* been reported, in this case parasitizing *A. mellifera* colonies (Mossadegh and Bahreini 1994).

The three *Acarapis* species are morphologically similar, and are usually identified by the location where they are observed on a honey bee host, in addition to specific morphological differences (Eckert 1961; Delfinado-Baker and Baker 1982). *A. externus* is the largest (Table 1). Examination of the distal line of the sternal plates is the most definitive defining feature of each species (Eckert 1961). Molecular tools have also been developed to identify *Acarapis* species (Evans et al. 2007). The total developmental time for *A. woodi* is 11 days, whereas *A. dorsalis* and *A. externus* take 8-9 days (Royce et al. 1988; Ibay 1989; de Guzman et al. 2001). Eckert (1961) claimed that a female *A. dorsalis* or *A. externus* can lay 2-5 eggs compared an average of 6 eggs for *A. woodi* (Royce et al. 1988).

Although all three *Acarapis* species feed on bee haemolymph, only *A. woodi* is considered to be of economic importance despite the death of colonies highly infested with *A. externus* (Ibay 1989; de Guzman et al. 2001). General symptoms of parasitism by *A. woodi*, at least in *A. indica* and *A. mellifera*, includes bees crawling in front of the hive, a distended abdomen, K-wing, and damaged trachea (Atwal 1971; Sammataro 2011). Virus-like particles have been observed in *A. woodi* (Liu 1991); however, thorough examinations of the potential for the mite to vector viruses like *Varroa* and *Tropilaelaps* mites are lacking.

388 4.2 Viruses

389 Viruses of honey bees are nearly ubiquitously distributed throughout the world, with
390 more than 18 isolated to date (Bailey and Ball 1991; Allen and Ball 1996; Chen and Siede
391 2007). Among them, seven are common including Black queen cell virus (BQCV), Deformed
392 wing virus (DWV), Kashmir bee virus (KBV), Sacbrood virus (SBV), Acute bee paralysis
393 virus (ABPV), Chronic bee paralysis virus (CBPV), and Israeli acute paralysis virus (IAPV)
394 (Chen and Siede 2007). In Asia, these seven viruses have been reported to infect different
395 honey bee species throughout the region (Sanpa and Chantawannakul 2009; Ai et al. 2012;
396 Forsgren et al. 2015). Based on their genomic structures, SBV and DWV are classified under
397 Iflaviridae whereas BQCV, ABPV, KBV and IAPV belong to the Dicistroviridae.

398

399 Iflaviridae

400 Of the viruses, Sacbrood virus (SBV) is the first virus discovered in *A. mellifera*
401 (White 1913). Historical records from Asia showed that Sacbrood disease was first detected in
402 *A. cerana* from Thailand in 1976 (Bailey et al. 1982). It was named Thailand sacbrood virus
403 (TSBV, also known as Chinese sacbrood virus) since it was serologically related to SBV but
404 physiochemically distinct (Bailey et al. 1982). TSBV caused death of greater than 90% of
405 domesticated *A.cerana* populations in Kashmir (Abrol and Bhat 1990), and was also found in
406 *A. dorsata* and *A. florea* in India (Allen and Ball 1996). In *A. cerana* it was observed in India,
407 Thailand, South Korea, Japan, Nepal, China, and Vietnam (Shah and Shah 1988; Allen and
408 Ball 1996; Choi et al. 2010; Kojima et al. 2011; Grabensteiner et al. 2007; Ai et al. 2012;
409 Forsgren et al. 2015). SBV infection of *A. mellifera* colonies was detected in Thailand, South
410 Korea, Japan, China, and Vietnam (Sanpa and Chantawannakul 2009; Yoo and Yoon 2009;
411 Kojima et al. 2011; Ai et al. 2012; Forsgren et al. 2015).

412 DWV appears to be more prevalent than SBV in four honey bee hosts. In *A. mellifera*,
413 it was detected in Sri Lanka, Nepal, Thailand, Japan, China, and Vietnam (Berènyi et al.
414 2007; Sanpa and Chantawannakul 2009; Kojima et al. 2011; Ai et al. 2012; Forsgren et al.
415 2015). DWV infections of *A. cerana* have been reported in China, South Korea, Japan, and
416 Vietnam, (Kojima et al. 2011; Ai et al. 2012; Li et al. 2012; Forsgren et al. 2015), and in *A.*
417 *florea* and *A. dorsata* in China (Zhang et al. 2012). The virus was detected in *V. destructor*
418 and *T. mercedesae* mites, and higher levels of DWV were detected in *A. mellifera* infested by
419 the mites in Thailand (Chantawannakul et al. 2006; Khongphinitbunjong et al. 2015).

420 Dicistroviridae

421 Black queen cell virus (BQCV) was first isolated from queen larvae and pupae of *A.*
422 *mellifera* found dead within their cells (Bailey and Woods 1977). The virus is highly
423 prevalent in *A. mellifera* in Thailand, South Korea, China, Japan, and Vietnam (Sanpa and
424 Chantawannakul 2009; Ai et al. 2012; Yang et al. 2013; Reddy et al. 2013; Kojima et al.
425 2011; Forsgren et al. 2015), in *A. cerana* in South Korea, China, Vietnam, Thailand, and
426 Japan (Li et al. 2012; Choe et al. 2012; Yang et al. 2013; Forsgren et al. 2015; Mookploy et
427 al. 2015), and in *A. florea* and *A. dorsata* from China and Thailand (Zhang et al. 2012;
428 Mookploy et al. 2015). Genetic variations of BQCV strains across four species of honey bees
429 have been studied. Based on the capsid coding region, the phylogenetic analysis revealed that
430 BQCV isolates from northern Thailand, China, South Korea, and Japan displayed a close
431 relationship within Asia and split separately from South Africa and European regions,
432 regardless of the host bee species from which the samples originated (Mookploy et al. 2015).
433 Similar findings were reported with the BQCV strains in Korea and Japan where the viral
434 isolates from the same country or continent showed high levels of similarity (Kojima et al.
435 2011; Noh et al. 2013). The role of BQCV in honey bee mortality is currently poorly

436 understood, particularly in association with other parasites such as the microsporidian *Nosema*
437 *apis* (Bailey et al. 1983).

438 ABPV, KBV and IAPV are part of a complex of related viruses (Chen and Siede
439 2007; de Miranda et al. 2010). KBV was first confirmed in *A. cerana* in India (Bailey and
440 Woods 1977), and subsequently in South Korea (Choe et al. 2012). Surveys of bee viruses in
441 *A. mellifera* colonies found KBV in Thailand (Sanpa and Chantawannakul 2009).
442 Interestingly, KBV was not found in China and Vietnam during the disease surveys in both *A.*
443 *cerana* and *A. mellifera* (Ai et al. 2012; Forsgren et al. 2015). ABPV has only been detected
444 in *A. cerana* (Choe et al. 2012), and in *A. mellifera* in China (Ai et al. 2012; Forsgren et al.
445 2015) and Thailand (Sanpa and Chantawannakul 2009). IAPV has been detected in both *A.*
446 *mellifera* and *A. cerana,* in *A. mellifera* in China (Ai et al. 2012), South Korea (Reddy et al.
447 2013), Japan (Morimoto et al. 2012) and Isarael (Maori et al. 2007), and in *A. cerana* in China
448 (Ai et al. 2012) and Japan (Kojima et al. 2011).

449 These viruses have been associated with honey bee colony losses, particularly when
450 colonies are co-infested with *V. destructor* (Cox-Foster et al. 2007; de Miranda et al. 2010). In
451 northern Thailand, KBV was only found when *V. destructor* prevalance was high in *A.*
452 *mellifera* colonies (Sanpa and Chantawannakul 2009).

453

454 4.3 Fungi

455 *Nosema* spp.

456 Two species of parasites belonging to this genus are known to infect honey bees, and
457 both occur in Asia (Klee et al. 2007). *N. apis,* first described in the early 1900s in Europe
458 (Zander 1909), is believed to historically parasitize *A. mellifera* (Fries 1993). *N. ceranae*

appears to have an Asian origin (Botías et al. 2012) since it was first detected in *A. cerana* in China in the late 1990s (Fries et al. 1996).

Surveys have identified *N. apis* in *A. mellifera* (e.g. Klee et al. 2007) and *A. cerana* (Rice 2001) only. In contrast, *N. ceranae* parasitizes a broader array of hosts such as *A. mellifera*, *A. cerana*, *A. florea*, *A. dorsata*, and *A. koschevnikovi* (e.g. Klee et al. 2007; Chaimanee et al. 2010; Botías et al. 2012). Although both parasites have been detected throughout the region, *N. ceranae* appears to be more widespread (Fig. 5A&B). In *A. mellifera*, *N. ceranae* was identified in Taiwan (Huang et al. 2007), Vietnam (Klee et al. 2007), China (Liu et al. 2008), Thailand (Chaimanee et al. 2010), Turkey (Whitaker et al. 2011), Indonesia (Botías et al. 2012), Solomon Islands (Botías et al. 2012), Japan (Yoshiyama and Kimura 2011), and Jordan (Haddad 2014). *N. apis* was detected in Israel (Gatehouse and Malone 1999), Indonesia (Rice 2001), and Turkey (Whitaker et al. 2011). *A. mellifera* colonies in China (Liu et al. 2008), Thailand (Chaimanee et al. 2010) or Jordan (Haddad 2014) were not infected with *N. apis*. Investigations of the incidence of *Nosema* spp. on honey bees native to Asia have been less thorough. In *A. cerana*, *N. ceranae* was identified in China, Vietnam, Indonesia, Solomon Islands, and Thailand (Fries et al. 1996; Klee et al. 2007; Li et al. 2012; Forsgren et al. 2015; Botías et al. 2012; Chaimanee et al. 2010), and also detected in *A. florea* and *A. dorsata* in Thailand (Chaimanee et al. 2010).

Studies comparing the phylogenetic relationships among *N. ceranae* isolated from four different honey bee species in Thailand using polar tube proteins, important for microsporidian host invasion, showed three distinct clades (Chaimanee et al. 2011). *N. ceranae* isolated from *A. mellifera* grouped into the same clade as *N. ceranae* isolated from *A. cerana*, while *N. ceranae* isolated from *A. florea* and *A. dorsata* formed distinct clades. *A. mellifera* and *A. cerana* are cavity-nesting honey bees, and are therefore more related to each other than to open-air, single comb-nesting species such as *A. dorsata* and *A. florea* (Alexander 1991). Therefore, the formation of a single clade for *N. ceranae* isolates from the

485 cavity-nesting species reflects the genetic lineage of *A. mellifera* and *A. cerana*, and
486 suggests ongoing co-evolution of this pathogen and its host. This is interesting considering
487 that the parasite supposedly came from *A. cerana*. In China however, studies using the 16 S
488 ribosomal RNA gene demonstrated that *N. ceranae* infecting *A. cerana* in the north and
489 south were distinct, and also different from *N. ceranae* circulating in *A. mellifera* worldwide.
490 Thai isolates fell into the same clade as those from southern China (Li et al. 2012).
491 Although *Nosema* are considered to be generalists, parasitizing a broad array of
492 honey bee hosts, their prevalence and intensity of infection are different for each species.
493 For *N. ceranae*, it appears that prevalence of infections in native honey bees is much lower
494 compared to *A. mellifera*, as colonies surveyed in Thailand revealed infection prevalences of
495 77.5 %, 22.2%, 45.4 %, and 37.5% for *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata*,
496 respectively (Chaimanee et al. 2010). When infected with *N. ceranae* obtained from *A.*
497 *mellifera* from Thailand, all four honey bee species became infected. However, different
498 levels of intensity were observed. Infection rate of *A. dorsata* was similar to that found in *A.*
499 *mellifera*, but *A. florea* was lower and *A. ceranae* the lowest (Chaimanee et al. 2011).
500 Suwannapong et al. (2011) also observed that *N. ceranae* isolated from *A. florea* could infect
501 *A. ceranae* and affect hypopharyngeal protein production and shorten their lifespan.
502 The virulence between *N. ceranae* strains from the original host *A. cerana* and *A.*
503 *mellifera* have been explored in these two cavity nesting species. *N. ceranae* isolated from
504 *A. mellifera* had higher infectivity than the isolate from *A. cerana* in both *A. mellifera* and *A.*
505 *cerana* (Chaimanee et al. 2013). It appears that no difference in infection rate occurred, but
506 rather each host species had displayed varied immune-related gene expression patterns in
507 response to the infection (Chaimanee and Chantawannakul *in press*).
508 In response to infection, *A. cerana w*orkers infected by *N. ceranae* tended to have
509 lower bacterial populations, particularly *Bifidobacterium* and Pasteurellaceae that produce
510 several antibiotic comounds important to host defense against parasites (Li et al. 2012). *N.*

511 *ceranae* may also promote the outbreak of other bee diseases, such as Chalkbrood (Hedtke
512 et al. 2011).
513 Both parasites can be managed by the fungicide fumagillin, but to varying degrees of
514 success that require further examination of timing and quantity of treatments (Akratanakul
515 1990; Williams et al. 2008; Williams et al. 2011; Huang et al. 2013).

516

517 *Ascosphaera apis*

518 The fungus *Ascosphaera apis*, which causes Chalkbrood disease in honey bees, was
519 first described in the early 20th century in *A. mellifera* in Europe (Maassen 1913), and now is
520 found throughout the world. In Asia, incidence of Chalkbrood has been reported in China,
521 Israel, Japan, Korea, the Philippines, Russia, Thailand and Turkey (Figure 5C) (Oldroyd and
522 Wongsiri 2006; Aronstein and Murray 2010). In Turkey, it was believed to have been
523 introduced from contaminated beeswax which was imported to the country (Tutkun et al.,
524 1993). In the Philippines and Thailand, beekeepers often reported higher incidence of fungal
525 infection during the wet season (Cervancia 1993; Chantawannakul and Puchanichanthranon
526 2005). Ingestion of the fungus by honey bee larvae allows *A. apis* to germinate within the gut
527 and eventually penetrate the body cavity, resulting in significant mechanical and enzymatic
528 damage; dead, dried larvae, named Chalkbrood mummies, can be observed within uncapped
529 brood cells (Heath 1982; Aronstein and Murray 2010). The fungus can produce lytic enzymes
530 (protease and beta-N-acetylglucosaminidase) that may be an important factor that assists
531 fungal invasion in the bee larvae; the enzymatic patterns from Thai isolates were similar to the
532 previous report of Spanish isolates (Theantana and Chantawannakul 2008). In *A.mellifera*,
533 Chalkbrood disease can result in lowered colony productivity, but rarely results in colony
534 death (Heath 1982; Aronstein and Murray 2010). It is also not considered to be a serious
535 disease of honey bees in Asia, even though it has been reported more widespread than

536 Stonebrood disease which is caused by the fungi from genus *Aspergillus* (Akratanakul 1990;
537 Ra et al. 2012) (Fig 5C and 5D).

538 4.4 Bacteria

539 *Paenibacillus larvae*

540 *Paenibacillus larvae*, the causative agent of a disease called American Foulbrood (AFB), has
541 a nearly ubiquitous distribution, including in Asia (Genersch 2010) (Fig 6 A). The disease
542 was found in *A. cerana* in India (Singh 1961) and *A. mellifera* in Taiwan (Yen and Chyn
543 1971). However, a survey conducted in 2003 in Thailand revealed that *A. mellifera* was free
544 of this disease (National Bureau of Agricultural Commodity and Food Standards 2008). Bee
545 larvae become infected when *P. larvae* spores are ingested; disease results in larvae that are
546 brownish, semi-fluid, and glue-like, before drying to a hard scale on the lower cell wall
547 (Genersch 2010). Scales are highly infective, and contain millions of spores that may be
548 infective for several decades (Hasemann 1961). When artificially fed spores of *P. larvae*, *A.*
549 *cerana* showed more resistance to infection than *A. mellifera* (Ho and Chen 2001).

550 *Melissococcus plutonius*

551 *Melissococcus plutonius* is a ubiquitously distributed bacterium of honey bees that has been
552 detected throughout Asia, including in *A. mellifera* (Akratanakul 1990), *A. cerana* (Diwan et
553 al. 1971; Bailey 1974; Zhou et al. 2000; Rana et al. 2012), *A. laboriosa* (Allen et al. 1990),
554 and *A. florea* (Saraithong et al. 2015) (Fig. 6B). *M. plutonius* primarily affects honey bee
555 larvae, causing a disease known as European foulbrood (EFB) that is characterized by dead,
556 twisted, brood within their cells. Infected colonies can be killed if a high proportion of larvae
557 are infected (Bailey and Ball 1991). EFB was detected in *A. mellifera* beekeeping in China,
558 Vietnam, Japan and Thailand (Forsgren et al. 2015; Aronstein and Murray 2010; Budge et al.
559 2010). In Thailand, EFB is particularly prevalent during the wet season (Akratanakul 1990). It
560 was also reported to cause serious damage to colonies of *A. cerana* in China between 1972-

1976 (Yang 2005), Vietnam (Chinh 1998; Forsgren et al. 2015), and recently in Japan (Arai et al. 2012; Takamatsu et al. 2014). A phenotypically and genetically distinct *M. plutonius* strain has been isolated from *A. cerana japonica*; it is frequently found and more virulent than the typical strain (Arai et al. 2014; Takamatsu et al. 2014).

4.5 Pests

4.5.1 Vertebrates

Bee-eating birds

Bee-eater birds are also troublesome to *A. mellifera*; they include the little green bee eater (*Merops orientalis*), the chestnut headed bee eater (*Merops leschenaulti*), the swifts (*Crypsiurus balasiensis*, *Chaetura* spp.), the white-vented needletail (*Hirundapus cochinchinesis*), the wood peckers (*Picus* spp.), the honeyguides (Indicatoridae), the black drongo (*Dicrurus macrocercus*), the ashy drongo (*D. leucophaeus*), and the greater racket-tailed drongo (*D. paradiseus*) (Akratanakul 1990; Cervancia 1993; Wongsiri et al. 2005). In some cases, beekeepers will employ net-trapping to limit bird predation, or relocate their colonies.

4.5.2 Invertebrates

Wax moths

Moth larvae attack the combs of honey bees worldwide. The greater wax moth, *Galleria mellonella*, and the lesser wax moth, *Achroia gisella*, are small non-descript moths that lay eggs in cracks and crevices of bee hives (Akratanakul 1990). Wax moths are a problem for unused or stored combs (Pernal and Clay 2013). Recently, larvae of *G. mellonella* attacking colonies of *A. cerana japonica* were collected in Japan. These samples also tested positive for IAPV and BQCV (Triyasut et al. *in press*). The viruses were likely horizontally

transmitted to the wax moth larvae by food or brood consumption within the colonies; however, viral replication in the wax moth larvae was not detected. Future work needs to clarify the possible role of bee viruses in moth larvae. In Southeast Asia, wax moths are a major pest of *A. cerana*, and causes them to abscond (Akratanakul 1990). Chemical controls are usually not applied for wax moth management. Instead, cultural measures such as removing hive debris, managing colonies to be strong, and removing or burning unused and infested combs are recommended.

Small hive beetle (*Aethina tumida*)

Aethina tumida is now an emerging pest of honey bees in Asia since it was discovered in the region for the first time in the Philippines in 2014 (Brion 2015). Between June 2014 and April 2015, hundreds of *A. mellifera* colonies in Mindanao (southern Philippines) had been lost from SHB infestation (Cervancia et al. submitted). The beetle is an opportunistic scavenger (Neumann and Elzen 2004). Mild climates of southern Asia provide an exceptional environment for *A. tumida*; high temperatures shorten the development period of the beetle (de Guzman and Frake 2007), and year-round availability of food (brood, pollen and honey) from multiple honey bee species promotes fecundity (de Guzman et al. 2014). Therefore, both native and introduced honey bee species, as well as stingless bees, are threatened by the beetle. Investigations are underway to adapt control measures employed in North America and Australia for the region.

Wasps (*Vespa* spp.)

Vespa spp. are important predators of honey bees in Asia (Matsuura 1988). Entrances of honey bee colonies are often targeted, with one wasp capable of capturing seven bees in one attack (Cervancia 1993). Such a disturbance can result in *A. cerana* colonies to abscond. Furthermore, some species are known to predate on *A. cerana* drones at drone congregation

areas (Koeniger et al. 1994). To deter predation, *A. cerana*, *A. nuluensis*, and *A. dorsata* perform body shaking as a defense mechanism (Koeniger et al. 1996; Kastberger et al. 1998; Tan et al. 2010; Khongphinitbunjong et al. 2012), and *A. cerana* and *A. mellifera* make tight balls that kill wasp intruders by heating (Ono et al. 1987; Tan et al. 2005). Beekeepers sometimes employ wasp traps or reduce the hive entrance, and also frequently kill wasps by hitting them with slippers, pieces of wood, or badminton rackets (Cervancia 1993). Furthermore, toxic baits may be used to poison wasp nest mates.

Ants

Many ant species can cause problems in commercial beekeeping. Most frequent recorded ant species are weaver ant (*Oecophylla smaragdina*), black ants (*Monomorium* spp.), fire ants (*Solenopsis* spp.) and *Formica* spp. (Akratanakul 1990).

Bee lice (*Braula coeca*)

Braula coeca wingless flies are not considered to be an important pest of honey bees (Pernal and Clay 2013). Larvae consume wax, pollen and honey, and tunnel through the combs. The adults eat nectar ad pollen, and steal food from the mouths of bees. Treatments for parasitic mites are also found effective against *B. coeca* (Kulincevic et al. 1991).

5. CONCLUSIONS & FUTURE PERSPECTIVES

With the introduction of *A. mellifera* in the region, native Asian honey bees are also at a greater risk of pathogen and parasite infections from inter-species transmission routes. Likewise, *A. mellifera* could be susceptible to further pests and parasites from native honey bees, which was previously exemplified by infestation by *V. destructor* and *N. ceranae* (Fries 2010; Rosenkranz et al. 2010). The rich diversity of honey bees, pathogens and parasites in

Asia has attracted researchers around the world to better understand host-parasite evolution and to improve management of introduced exotic parasites of *A. mellifera* that have come from Asia by studying those parasites with their indigenous hosts. Many reports suggest that native Asian honey bees cope well with parasites that are currently devastating to *A. mellifera* using behavioural and immunological host defense mechanisms (Khonphinitbunjong et al. 2012; Chaimanee et al. 2010). The migratory nature of several species of native Asian honey bees may also affect susceptibility of infection or infestation (Kavinseksan et al. 2003). The resistance of Asian honey bees towards some bacterial pathogens may be due to their unique bacterial community structures inhibiting pathogen growth or infection. Studies have shown that gut bacteria in *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata* differ, likely due to geographic location, life stage, and species of honey bees (Disayathanoowat et al. 2011, Saraithing et al. 2015, *in press*). Furthermore, some isolates of midgut bacteria inhibit growth of American foulbrood causing *P. larvae in vitro* (Disayathanoowat et al. 2011, 2012). Honey bee hives also harbor actinomycetes, the main microbial groups that produce natural antibiotics (Promnuan et al. 2009, 2011), and hive components such as propolis and bee bread could also assist in safeguarding against some pests and parasites (Simone-Finstrom and Spivak 2012; Simone et al. 2009). Additionally, other non-biological factors and management problems that plague not just honey bees, but other bees, could also result in decreased honey bee health in Asia. Increasing loss of foraging resources due to farming and urban encroachment may strain populations (Naug 2009). Pesticide exposure could also present high risks to honey bees, and a recent study revealed that organophosphates are highly toxic to *A. cerana* and *A. mellifera* (Stanley et al. 2015). The current policy of pollinator protection, especially honey bees, has not yet been successfully implemented in the region as honey bees are often undervalued or the value of honey bees is completely overlooked. Scientific information of honey bee pests and parasites in some regions are still lacking. In addition,

standards and research on biomedical properties of bee products, such as honey (Wanjai et al. 2012) and propolis (Sanpa et al. 2015), are needed to promote beekeeping in Asia.

Acknowledgement

P.C. would like to thank the Thailand Research Fund, National Research Council of Thailand and Chiang Mai University fund. G.R.W. thanks the Vinetum Foundation.

References

Abrol, D.P., Bhat, A.A. (1990) Studies on Thai sac brood virus affecting indigenous honey bee *Apis cerana indica* Fab. Colonies-prospects and future strategies. J. Anim. Morphol. Physiol. **37**, 101-108

Abrol, D.P., Putatunda, B. N. (1995) Discovery of an ectoparasitic mite *Tropilaelaps koenigerum* Delifinado-Baker & Baker on *Apis dorsata, A. meliffera* L. and *Apis cerana* F. in Jammu and Kashmir, India. Current Sci. **68**, 90

Ai, H., Yan, X., Han, R. (2012) Occurrence and prevalence of seven bee viruses in *Apis mellifera* and *Apis cerana* apiaries in China. J. Invertebr.Pathol.**109**, 160–164

Akratanakul, P. (1975) Biology and systematics of bee mites of the family Varroidae (Acari: Mesostigmata). MS Thesis. Oregon State University. pp 1-64

Akratanakul, P. (1990) Beekeeping in Asia. FAO (Food and Agriculture Organisation of the United Nations), Agricultural Services. Bulletin 68/4. Rome, Italy.

Alexander, B. (1991) A cladistics analysis of the genus *Apis*, in: Smith, D.R. (Ed.), Diversity in the Genus *Apis*. Westview Press, Boulder, pp. 1-28

Allen, M. R., Ball, B.V. (1996) The incidence and world distribution of honey bee viruses. Bee World **77**, 141-162

Allen, M.F. Ball, BV. Underwood, B.A. (1990) An isolate of *Melissococcus pluton* from *Apis laboriosa*. J. Invertebr. Pathol. **55**, 439-440

687 Amr, S.Z., Shehada, S. E., Abo-Shehada, M., Al-Oran, R. (1998) Honeybee parasitic
688 arthropods in Jordan. Apiacta **3**,78-82
689 Anderson, D.L. (1994) Non-reproduction of *Varroa jacobsoni* in *Apis mellifera* colonies in
690 Papua New Guinea and Indonesia. Apidologie **25**, 412-421
691 Anderson, D.L. (2004) Varroa mites and their host relationships in the Philippines.
692 Proceedings of the 7th Asian apicultural Association Conference and 10th Beenet
693 Symposium and Technoflora, Laguna, Luzon, Philippines, pp. 177-178
694 Anderson, D.L., Sukarsih, D. (1996) Changed *Varroa jacobsoni* reproduction in *Apis*
695 *mellifera* colonies in Java. Apidologie **27**, 461-466
696 Anderson, D.L., Fuchs, S. (1998) Two genetically distinct populations of *Varroa jacobsoni*
697 with contrasting reproductive abilities on *Apis mellifera*, J. Apic. Res. **37**, 69-78
698 Anderson, D. L., Trueman, J. W. H. (2000) *Varroa jacobsoni* (Acari: Varroidae) is more than
699 one species. Exp. Appl. Acarol. **24**, 165-189
700 Anderson, D.L., Morgan, M.J. (2007) Genetic and morphological variation of bee-parasitic
701 *Tropilaelaps* mites (Acari: Laelapidae): new and re-defined species. Exp. Appl.
702 Acarol. **43**, 1-24
703 Anderson, D.L., Halliday, R.B., Otis, G.W. (1997) The occurrence of *Varroa underwoodi*
704 (Acarina: Varroidae) in Papua New Guinea and Indonesia. Apidologie **28**, 143–147
705 Arai, R., Tominaga, K., Wu, M., Okura, M., Ito, K., Okamura, N., Onishi, H., Osaki, M.,
706 Sugimura, Y., Yoshiyama, M., Takamatsu, D. (2012) Diversity of *Melissococcus*
707 *plutonius* from honey bee larvae in Japan and experimental reproduction of European
708 foulbrood with cultured atypical isolates. PLoS ONE **7**, e33708
709 Arai, R., Miyoshi-Akiyama, T., Okumura, K., Morinaga, Y., Wu, M., Sugimura, Y.,
710 Yoshiyama, M., Okura, M., Kirakae, T., Takamatsu, D. (2014) Development of
711 duplex PCR assay for detection and differentiation of typical and atypical
712 *Melissococcus plutonius* strains. J. Vet. Med. Sci. **76**, 491-498

713 Aronstein, K.A., Murray, K.D. (2010) Chalkbrood disease in honey bees. J. Invertebr. Pathol.
714 **103**, S20–S29
715 Atwal, A.S. (1971) Acarine disease problem of the Indian honey bee, *Apis indica* F. Am. Bee
716 J. 111, 186-187
717 Bailey, L. (1974) An unusal type of *Streptococcus pluton* from eastern hive bee. J. Invertebr.
718 Pathol. **23**, 246-247
719 Bailey, L. Ball, B.V. (1991) Honey Bee Pathology. Academic Press Ltd., London. pp 193
720 Bailey, L. Woods, R.D. (1977) Two more small RNA viruses from honey bees and further
721 observations on sacbrood and acute bee-paralysis viruses. J. Gen. Virol. **37** (1), 175-
722 182
723 Bailey, L., Ball, B.V., Perry, J.N. (1983) Association of viruses with two protozoal pathogens
724 of the honey bee. An. Appl. Biol. **103**, 13-20
725 Bailey, L., Ball, B.V., Carpenter, J.M., Woods, R.D. (1982) A strain of sacbrood virus from
726 *Apis cerana*. J. Invertebr. Pathol. **39**, 264-265
727 Beetsma, J., Boot, W.J., Calis, J. (1999) Invasion behavior of *Varroa jacobsoni* Oud from
728 bees into brood cells. Apidologie **30**, 125-140
729 Berényi, O., Bakonyi, T., Derakhshifar, I., Koglberger, H., Topolska, G., Ritter, W.
730 Pechhacker, H., Nowotny, N. (2007) Phylogenetic analysis of deformed wing virus
731 genotypes from diverse geographic origins indicates recent global distribution of the
732 virus. Appl. Environ. Microbiol. **73**, 3605-3611
733 Botías, C., Anderson, D.L., Meana, A., Garrido-Bailón, E., Martín-Hernández, R., Higes, M.
734 (2012) Furthur evidence of an oriental origin for *Nosema ceranae* (Microsporidia:
735 Nosematidae). J. Invertebr. Pathol. **110** (1), 108-113
736 Booppha, B., Eittsayeam, S., Pengpat, K., Chantawannakul, P. (2010) Development of
737 bioactive ceramics to control mite and microbial diseases in bee farms. Advanced
738 Materials Research **93**, 553-557

739 Brion, A.C. B. (2015) Small hive beetle poses threat to bee industry. The Philippine
740 Star (February 22)
741 Buawangpong, N., Khongphinitbunjong, K., Chantawannakul, P., Burgett, M. (2013)
742 *Tropilaelaps mercedesae*: Does the honey bee brood mite parasite exhibit a gender
743 preference when infesting brood of the adapted host *Apis dorsata*?,J. Apic. Res. **52**,
744 158-159
745 Buawangpong, N., de Guzman, L.I., Frake, A.M., Khongphinitbunjong, K., Burgett, M.,
746 Chantawannakul, P. (2015) *Tropilaelaps mercedesae* and *Varroa destructor*:
747 prevalence and reproduction in concurrently infested *Apis mellifera* colonies.
748 Apidologie 1-8; DOI: 10.1007/s13592-015-0368-8
749 Büchler, R., Drescher, W., Tornier, I. (1992) Grooming behaviour of *Apis cerana*, *Apis*
750 *mellifera* and *Apis dorsata* and its effects on the parasitic mites *Varroa jacobsoni* and
751 *Tropilaelaps clareae*, Exp. Appl. Acarol. **16**, 313-319
752 Budge, G.E., Barrett, B., Jones, B., Pietravalle, S., Marris, G., Chantawannakul, P., Thwaites,
753 R., Hall, J., Cuthbertson, A.G., Brown, M.A. (2010) The occurrence of *Melissococcus*
754 *plutonius* in healthy colonies of *Apis mellifera* and the efficacy of European foulbrood
755 control measures. J. Invertebr. Pathol. **105**, 164-70
756 Burgett, D. M., Akratanakul, P., Morse, R. (1983) *Tropilaelaps clareae*: A parasite of honey
757 bees in South East Asia. Bee world **64**, 25-28
758 Burgett, D.M., Kitprasert, C. (1990) Evaluation of Apistan™ as a control for *Tropilaelaps*
759 *clareae* (Acari: Laelapidae), an Asian honey bee brood mite parasite. Am. Bee J. **130**,
760 51–53
761 Cervancia, C.R. (1993) Philippines beekeeping status of research and development, in: Proc.
762 Beenet Asia: workshop on priorities in R&D on beekeeping in tropical Asia. Kuala
763 Lumpur, Malaysia. pp. 49-63

764 Cervancia, C.R., de Guzman, L.I., Polintan, E.A. Locsin, A.A. (submitted) A scientific note
765 on the current status of small hive beetle infestation in the Philippines. Apidologie.
766 Chaimanee, V., Chantawannakul, P. (In Press) Infectivity of *Nosema ceranae* isolated from
767 *Apis cerana* and *A. mellifera*. J. Apic. Res.
768 Chaimanee, V., Warrit, N., Chantawannakul, P. (2010) Infections of *Nosema ceranae* in four
769 different honeybee species. J. Invertebr Pathol. **105**, 207-210
770 Chaimanee, V., Chen, Y., Pettis, J.S., Scott Cornman, R.,Chantawannakul, P. (2011)
771 Phylogenetic analysis of *Nosema ceranae* isolated from European and Asian
772 honeybees in Northern Thailand. J. Invertebr. Pathol. **107**, 229-233
773 Chaimanee, V., Pettis, J. S., Chen, Y., Evans, J. D., Khongphinitbunjong, K.,
774 Chantawannakul, P. (2013) Susceptibility of four different honey bee species to
775 *Nosema ceranae*. Vet. Parasitol. **193**(1-3), 260-265
776 Chantawannakul, P., Puchanichanthranon, T. (2005) Inhibitory effects of some medicinal
777 plant extracts on the growth of *Ascosphaera apis*. Acta Hort. **678**, 183-186
778 Chantawannakul, P., Ward, L., Boonham, N. & Brown, M. (2006) A scientific note on the
779 detection of honeybee viruses using real-time PCR (TaqMan) in *Varroa* mites
780 collected from a Thai honeybee (*Apis mellifera*) apiary. J. Invertebr. Pathol. **91**, 69-73
781 Chen, Y. P., Siede, R. (2007) Honey bee viruses, in: Karl Maramorosch, A.J.S., Frederick,
782 A.M (Eds.), Advances in Virus Research. Academic Press 70, pp. 33-80
783 Choe, S. E., Nguyen, L. T. K., Noh, J. H., Koh, H. B., Jean, Y. H., Kweon, C. H., Kang, S. W.
784 (2012). Prevalence and distribution of six bee viruses in Korean *Apis cerana*
785 populations. J. Invertebr. Pathol. **109**(3), 330-333
786 Choi, Y.S. Lee, M.L., Lee, M.Y., Lee, K.G. (2008) Occurrence of seven honey bee viruses
787 and research of disease occurrence in Korean apiaries. Korean J. Apicul. **23**(2), 153-
788 159.
789 Cox-Foster, D.L., Conlan, S., Holmes, E.C., Palacios, G., Evans, J.D., et al. (2007) A

790 metagenomic survey of microbes in honey bee colony collapse disorder. Science **318**
791 (5848), 283-287
792 Crane, E. (1999) The world history of beekeeping and honey hunting. Gerald
793 Duckworth & Co. Ltd, London.
794 Crane, E. (2003) Making a bee-line International bee research association. International Bee
795 Research Association, Cardiff, United Kingdom.
796 Dainat, B., Tan, K., Berthoud, H., Neumann P. (2008) The ectoparasitic mite *Tropilaelaps*
797 *mercedesae* (Acari, Laelapidae) as a vector of honeybee viruses. Insectes Soc. **56**, 40-
798 43
799 De D'Aubeterre, J.P., Myrold, D.D., Royce, L.A., Rossignol, P.A. (1999) A scientific note
800 of an application of isotope ratio mass spectrometry to feeding by the mite,
801 *Varroa jacobsoni* Oudemans, on the honeybee, *Apis mellifera* L. Apidologie **30**,
802 351–352
803 de Guzman, L.I., Delfinado-Baker, M. (1996) A new species of *Varroa* (Acari: Varroidae)
804 associated with *Apis koschevnikovi* (Apidae: Hymenoptera) in Borneo. Internat. J.
805 Acarol. **22**, 23-27
806 de Guzman, L.I., Rinderer, T.E. (1998) Distribution of the Japanese and Russian genotypes
807 of *Varroa jacobsoni.* Honey Bee Sci. **19**, 115-119
808 de Guzman, L.I., Rinderer, T. E. (1999) Identification and comparison of *Varroa* species
809 identification and comparison of *Varroa* species infesting honey bees. Apidologie **30**,
810 85-95
811 de Guzman, L.I., Frake, A.M. (2007) Temperature affects *Aethina tumida* (Coleoptera:
812 Nitidulidae) development. J. Apic. Res. **46**, 88-93
813 de Guzman, L.I., Rinderer, T.E., Whiteside, R. (1996) Scientific note on the infestation of
814 *Varroa* on *Apis nuluensis*. Apidologie **27**,429-430

de Guzman, L.I., Rinderer, T.E., Stelzer, J.A. (1997) DNA evidence of the origin of *Varroa jacobsoni* Oudemans in the Americas. Biochem. Genet. **35**, 327-335

de Guzman, L.I., Rinderer, T.E., Stelzer, J. A. (1999) Occurrence of two genotypes of *Varroa jacobsoni* Oud. in North America. Apidologie **30**, 31-36

de Guzman L.I., Burgett D.M., Rinderer T. E. (2001) Biology and life history of *Acarapis dorsalis* and *Acarapis externus*, in: Webster, T. C. and Delaplane, K. S. (Eds) Mites of the honey bees. Dadant, Hamilton, IL, pp.17-27

de Guzman, L.I, Rinderer, T.E., Frake, A.M. (2014) Effects of diet, mating and temperature on ovary activation and fecundity of small hive beetles (Coleoptera: Nitidulidae). Apidologie, DOI:10.1007/s13592-014-0325-y

de Guzman, L.I., Rinderer, T.E., Stelzer, J.A., Anderson, D.L. (1998) Congruence of RAPD and mitochondrial DNA markers in assessing *Varroa jacobsoni* genotypes. J. Apic. Res. **37**, 49-51

de Jong, D. (1988) *Varroa jacobsoni* does reproduce in worker cells of *Apis cerana* in South Korea. Apidologie **19**, 241-244

de Miranda, J.R., Cordoni, G., Budge, G (2010) The Acute bee paralysis virus–Kashmir bee virus–Israeli acute paralysis virus complex. J. Invertebr. Pathol. **103**, Supplement, S30-S47

Delfinado, M., Baker, E.W. (1961) *Tropilaelaps*, a new genus of mites from the Philippines (Laelaptidae[s.lat]: Acarina). Fieldiana Zool. **44**, 53-56

Delfinado, M D., Baker, E.W. (1974) Varroidae, a new family of mites on honey bees (Mesostigmata: Acarina). J. Wash. Acad. Sci. **64**, 4-10

Delfinado, M D., Baker, E.W. (1982) Notes on the honey bee mites of the genus *Acarapis* Hirts (acari: Tasrsonemidae). Internat. J. Acarol. **8**, 211-226

839 Delfinado-Baker, M. (1982) New records for *Tropilaelaps clareae* from colonies of *Apis*
840 *cerana indica.* Am. Bee J. **122**, 382
841 Delfinado-Baker, M., Baker, E.W. (1982) A new species of *Tropilaelaps* parasitic on honey
842 bees. Am. Bee J. **122**,416-417
843 Delfinado-Baker, M., Aggarwal, K. (1987) A new *Varroa* (Acari: Varroidae) from the nests
844 of *Apis cerana* (Apidae). Int. J. Acarol. **13**, 233-237
845 Delfinado-Baker, M., Baker, E.W., Phoon, A.C.G. (1989) Mites (Acari) associated with bees
846 (Apidae) in Asia, with description of a new species. Am. Bee J. **129**, 609-610, 612-
847 613
848 Delfinado-Baker, M., Underwood, B.A., Baker, E.W. (1985) The occurrence of *Tropilaelaps*
849 mites in brood nests of *Apis dorsata* and *A. laboriosa* in Nepal, with descriptions of
850 nymphal stages. Am. Bee J. **125**, 703-706
851 Diwan, V.V., Kshirsagar, K.K., Ramama Rao, A.V., Raghunath, D., Bhambure, C.S.,
852 Godbole, S.H. (1971) Occurrence of a new bacterial disease of Indian honey bee *Apis*
853 *indica*.F. Curr. Sci. **40**, 196.197
854 Disayathanoowat, T., Young, J. P. W., Helgason, T., Chantawannakul, P. (2011) T-RFLP
855 analysis of bacterial communities in the midguts of *Apis mellifera* and *Apis cerana*
856 honey bees in Thailand. FEMS Microbiol. Ecol. **79** (2), 273-281
857 Disayathanoowat, T., Yoshiyama, M., Kimura, K., Chantawannakul, P. (2012) Isolation and
858 characterization of bacteria from the midgut of the Asian honey bee (*Apis cerana*
859 indica). J. Apic. Res. **51**(4), 312-319
860 Donzé, G., Herrmann, M., Bachofen, B., Guerin, P.R.M. (1996) Effect of mating frequency
861 and brood cell infestation rate on the reproductive success of the honeybee parasite
862 *Varroa jacobsoni.* Ecol. Entomol. **21**, 17-26
863 Eckert, J. E. (1961) *Acarapis* mites of the honey bee, *Apis mellifera* L. J. Insect Pathol. **3**,
864 409-425

865 Ellis, J.D., Munn P.A. (2005) The worldwide health status of honey bees. Bee World **86**, 88-
866 101
867 Evans, J.D., Pettis, J.S., Smith, I.B. (2007) A diagnostic genetic test for the honey bee tracheal
868 mite, *Acarapis woodi*. J. Apic. Res. **46**, 195–197
869 Food and Agriculture Organization of the United Nartions (FAO) (2014)
870 FAOSTAT.(http://faostat.fao.org)
871 Fries, I. (1993) *Nosema apis* - a parasite in the honey bee colony. Bee World **74**(1), 5–19
872 Fries, I. (2010) *Nosema ceranae* in European honey bees (*Apis mellifera*). J.
873 Invertebr. Pathol. **103**, S73-S79
874 Fries, I., Feng, F., Da Silva, A., Slemenda, S.B., Pieniazek, N.J. (1996) *Nosema ceranae* n. sp.
875 (Microspora, Nosematidae), morphological and molecular characterization of a
876 microsporidian parasite of the Asian honey bee *Apis cerana* (Hymenoptera, Apidae).
877 Eur. J. Protistol. **32** (3), 356-36
878 Fries, I., Martín, R., Meana, A., García-Palencia, P., Higes, M. (2006). Natural infections of
879 *Nosema ceranae* in European honey bees. J. Apic. Res. **45** (4), 230-233
880 Forsgren, E., de Miranda, J.R., Isaksson, M., Wei, S., Fries, I. (2009) Deformed wing virus
881 associated with *Tropilaelaps mercedesae* infesting European honey bees (*Apis*
882 *mellifera*). Exp. Appl. Acarol. **47**, 87-97
883 Forsgren, E., Wei, S., Guiling, D., Zhiguang, L., Tran, T.V., Tang, P.T., Truong, T.A., Dinh,
884 T.Q., Fries, I. (2015) Preliminary observations on possible pathogen spill-over from
885 *Apis mellifera* to *Apis cerana*. Apidologie **46**, 265-275
886 Fuchs, S., Long, L., Anderson, D. (2000) A scientific note on the genetic distinctness of
887 *Varroa* mites on *Apis mellifera* L. and on *Apis cerana* Fabr. in North Vietnam.
888 Apidologie **31**, 456-460
889 Gatehouse, H.S., Malone, L.A. (1999) Genetic variability among *Nosema apis* isolates. J.
890 Apic. Res. **38**, 79–85

Genersch, E. (2010) American Foulbrood in honeybees and its causative agent, *Paenibacillus larvae*. J. Invertebr. Pathol. **103**, S10-19.

Gerson, U., Dag, A., Efrat, C., Slabezki, Y., Stern, Y. (1994) Tracheal mite, *Acarapis woodi*, comes to Israel. Am. Bee J. **134**, 486

Grabensteiner, E., Bakonyi, T. Ritter, W., Pechhacker, H., Nowotny, N. (2007) Development of a multiplex RT-PCR for the simultaneous detection of three viruses of the honeybee (*Apis mellifera* L.): Acute bee paralysis virus, Black queen cell virus and Sacbrood virus. J. Invertebr. Pathol. **94**(3), 222-225

Haddad, N. J. (2014) First detection of *Nosema ceranae* in Jordan. Eur. Sci. J. **10** (33), 91-96

Hasemann, L. (1961) How long can spores of American foulbrood live? Am. Bee J. **101**, 298-299

He, X., Liu, X.Y. (2011) Factor of *Apis ceranae* decline in China. Apiculture of China **62**(5), 21-23

Heath, L.A.F. (1982) Development of chalk brood in a honey bee colony; Chalkbrood pathogens: a review. Bee World **63** (3), 119–135

Hedtke, K., Jensen, P.M., Bruun, A., Genersch, E. (2011) Evidence for emerging parasites and pathogens influencing outbreaks of stress-related diseases like chalkbrood. J. Invertebr. Pathol. **108**, 167–173

Hepburn, H.R., Hepburn, C. (2005) Bibliography of *Apis florea*. Apidologie **36**, 377-378. DOI 10.1051/apido:2005024

Hepburn, R., Hepburn C. (2006) Bibliography of *Apis cerana* Fabricius (1793). Apidologie **37**, 651-652. DOI 10.1051/apido:2006038

Hepburn, R., Radloff, S.E. (2011). Honeybees of Asia: Springer Berlin Heidelberg. 669 pp.

Hepburn, H.R., Radloff, S.E., Verma, S., Verma, L.R. (2001) Morphometric analysis of *Apis cerana* populations in the southern Himalayan region. Apidologie **32**, 435-447

916 Hepburn, H.R., Radloff, S.E., Otis, G.W., Fuchs, S., Verma, L.R., Tan, K., Chaiyawong, T.,
917 Tahmasebi ,G., Ebadi, R., Wongsiri, S. (2005) *Apis florea*: morphometrics,
918 classification and biogeography. Apidologie 36: 359-376. DOI: 10.1051/apido:2005023
919 Ho, K., Chen, Y. (2001) Susceptibility of the Asian honey bee (*Apis cerana*) to American
920 foulbrood (*Paenibacillus larvae larvae*). Proceeding of the 37th International
921 Apicultural Congress. Durban, South Africa, pp. 1-8
922 Huang, W.F., Jiang, J. H., Chen Y. W., Wang, C. H. (2007) A *Nosema ceranae* isolate from the
923 honeybee *Apis mellifera*. Apidologie **38**, 30-37
924 Huang, W. F., Solter, L.F., Yau, P.M., Imai, B.S. (2013) *Nosema ceranae* escapes fumagillin
925 control in honey bees. PLOS Pathogens **9** (3), e1003185
926 Ibay, L.I. (1989) Biology of the two external *Acarapis* species of honey bees: *Acarapis*
927 *dorsalis* Morganthaler and *Acarapis externus* Morganthaler (Acari: Tarsonemidae).
928 Oregon State University. USA.
929 Ifantidis, M. (1990) Re-examination of the reproductive parameters of the mite *Varroa*
930 *jacobsoni* Oudemans. Proc. Int. Symp. Bee Pathol. Gent, Belgium, pp. 20-26
931 Kapil, R.P., Aggarwal, K. (1987) Some observations on the concurrent parasitization of *Apis*
932 *florea* by *Tropilaelaps clareae* and *Euvarroa sinhai*. Exp. Appl. Acarol. **3**, 267-269
933 Kastberger, G., Raspotnig, G., Biswas, S., Winder, O. (1998) Evidence of Nasonov scenting
934 in colony defence of the Giant honeybee *Apis dorsata*, Ethology **104**, 27-37
935 Kavinseksan, B., Wongsiri, S., de Guzman, L.I., Rinderer, T.E. (2003) Absence of
936 *Tropilaelaps* infestation from recent swarms of *Apis dorsata* in Thailand. J. Apic. Res.
937 **42**, 49-50
938 Khongphinitbunjong, K., de Guzman, L., Burgett, M., Rinderer, T., Chantawannakul, P.
939 (2012) Behavioral responses underpinning resistance and susceptibility of honeybees
940 to *Tropilaelaps mercedesae*. Apidologie **43**, 590-599

941 Khongphinitbunjong, K., de Guzman, L. I., Buawangpong, N., Rinderer, T. E., Frake, A. M.,
942 Chantawannakul, P. (2014). Observations on the removal of brood inoculated with
943 Tropilaelaps mercedesae (Acari: Laelapidae) and the mite's reproductive success in
944 *Apis mellifera* colonies. Exp. Appl. Acarol. **62**(1), 47-55
945 Khongphinitbunjong, K., de Guzman, L.I., Tarver, M.R., Rinderer, T.E., Chantawannakul P.
946 (2015) Interactions of *Tropilaelaps mercedesae*, honey bee viruses and immune
947 responses in *Apis mellifera*. J. Apic Res., DOI:10/1080/00218839.2015.1041311
948 Kirrane, M., de Guzman, L.I., Rinderer, T.E., Frake, A.M., Wagnitz, J., Whelan, P. M. (2011)
949 Asynchronous development of honey bee host and *Varroa destructor* influences
950 reproductive potential of mites. J. Econ. Entomol. **104**, 1146-1152
951 Kitprasert, C. (1984) Biology and systematics of the parasitic mite, *Tropilaelaps clareae*
952 Delfinado and Baker (Acarina: Laelapidae), M.S. Thesis, Kasetsart University,
953 Thailand (in Thai).
954 Kitprasert, C. (1995) Parasitism by the brood mite, *Euvarroa sinhai* Delfinado and Baker
955 (Acari: Varroidae) on the dwarf honey bee, *Apis florea* F. (Hymenoptera: Apidae) in
956 Thailand. Ph.D. Dissertation. Oregon State University. pp. 1-96
957 Klee, J., Besana, AM., Genersch, E., Gisder, S., Nanetti, A., et al. (2007) Widespread
958 dispersal of the microsporadian *Nosema ceranae* and emergent pathogen of western
959 honey bee, *Apis mellifera*. J. Invertebr. Pathol. **96**, 1-10
960 Koeniger, N., Koeniger, G., Delfinado-Baker, M. (1983) Observations on mites of the Asian
961 honey bee species. Apidologie **14**, 197-204
962 Koeniger, G., Koeniger, N., Anderson, D.L., Lekprayoon, C., Tingek, S. (2002) Mites from
963 debris and sealed brood cells of *Apis dorsata* colonies in Sabah (Borneo) Malaysia,
964 including a new haplotype of *Varroa jacobsoni*. Apidologie **33**, 15–24
965 Koeniger, N, Musaffar, N. (1988) Lifespan of the parasitic honeybee mite, *Tropilaelaps*
966 *clareae*, on *Apis cerana*, *A. dorsata* and *A. mellifera*. J. Apic. Res. **27**, 207-212

967 Koeniger, N., Koeniger, G., Mardan, M. (1994) Mimicking a honeybee queen? *Vespa affinis*
968 *indosinensis* Pérez 1910 hunts drones of *Apis cerana* F. Ethology **98**, 149-153
969 Koeniger, N., Koeniger, G., de Guzman, L.I., Lekprayoon, C. (1993) Survival of *Euvarroa*
970 *sinhai* Delfinado and Baker (Acari, Varroidae) on workers of *Apis cerana* Fabr, *Apis*
971 *florea* Fabr. and *Apis mellifera* L. in cages. Apidologie **24**, 403-410
972 Koeniger, N., Koeniger, G., Gries, M., Tingek, S., Kelitu, A. (1996) Observations on colony
973 defense of *Apis nuluensis* and predatory behaviour of the hornet, *Vespa multimaculata*
974 Pérez, 1910. Apidologie **27**, 341-352
975 Kojima, Y., Toki, T., Morimoto, T., Yoshiyama, M., Kimura, K., Kadowaki, T. (2011)
976 Infestation of Japanese native honey bees by tracheal mite and virus from non-native
977 European honey bees in Japan. Microbiol. Ecol. **62**, 895-906
978 Kulincevic, J.M., Rinderer, T.E., Mladjan, V.J (1991) Effects of fluvalinate and amitraz on
979 bee lice (Braula-Coeca Nitzsch) in honey bee (*Apis mellifera* L.) colonies in
980 Yugoslavia. Apidologie **22**, 43-47
981 Laigo, F.M., Morse, R.A. (1968) The mite *Tropilaelaps clareae* in *Apis dorsata* colonies in
982 the Philippines. Bee World **49**, 116–118
983 Lekprayoon, C, Tangkanasing P. (1991) *Euvarroa wongsirii*, a new species of bee mite from
984 Thailand. Internat. J. Acarol. **17**, 255-258
985 Li, J. Qin, H., Wu, J., Sadd, B.M., Wang, X., Evans J.D., Peng W. (2012) The prevalence of
986 parasites and pathogens in Asian honey bees *Apis cerana* in China. PLOS one **7**(11),
987 e47955. 1-12
988 Liu, T.P. (1991) Virus-like particles in the tracheal mite Acarapis-woodi (Rennie). Apidologie
989 **22**, 213-219
990 Liu, F. Wang, Q, Dai, P.L., Wu, Y.Y. Song, H.K., Zhou, T. (2008) Natural stripe of
991 microsporadia of honey bee in China. Chinese Bull. Entomol. **45**, 963-966

992 Lo, N., Gloag, R.S., Anderson, D.L. Oldroyd, B.P. (2010) A molecular phylogeny of the
993 genus *Apis* suggests that the giant honey bee of the Philippines, *A. breviligula*
994 Maa, and the plains honey bee of southern India, *A. indica* Fabricius, are valid
995 species. Syst. Entomol. **35** (2), 226–233
996 Maassen, A. (1913) Weitere Mitteilungen uber der seuchenhaften Brutkrankheiten
997 der Bienen [Further communication on the epidemic brood disease of bees].
998 Mitteilungen aus der Kaiserlichen Biologischen Anstalt fur Land- und
999 Forstwirtschaft **14**, 48–58
1000 Martin, S. (1998) A population model for the parasitic mite *Varroa jacobsoni* in honey bee
1001 (*Apis mellifera*) colonies. Ecol. Model. **109**, 267-281
1002 Matheson, A. (1993) World bee health report. Bee World **74**,176-212
1003 Matheson, A. (1995) World bee health report. Bee World **76**, 31-39
1004 Maori, E., Lavi, S., Mozes-Koch, R., Gantman, Y., Peretz, Y., Edelbaum, O., Tanne, E.,
1005 Sela, I. (2007) Isolation and characterization of Israeli acute paralysis virus, a
1006 Dicistrovirus affecting honeybees in Israel: evidence for diversity due to intra- and
1007 inter-species recombination. J. Gen. Virol. **88**, 3428-38
1008 Matsuura, M. (1988) Ecological studies on vespine wasps (Hymenoptera: Vespidae) attacking
1009 honeybee colonies. Appl. Entomol. Zool. **23**, 428-440
1010 Michael, D.S. (1957) Acarine disease found in India, Am. Bee. J. **97**,107
1011 Milne, P.S. (1957) Acarine disease in *Apis indica*, Bee World **38**, 156
1012 Mookhploy, W., Kimura, K., Disayathanoowat, T., Yoshiyama, M., Hondo, K.
1013 Chantawannakul, P. (2015) Capsid gene divergence of Black queen cell virus isolates
1014 in Thailand and Japan honey bee species. J. Econ. Entomol. 1–5, DOI:
1015 10.1093/jee/tov102
1016 Morimoto, T., Kojima, Y., Yoshiyama, M., Kimura, K., Yang, B., Kadowaki, T. (2012)

Molecular identification of chronic bee paralysis virus infection in *Apis mellifera* colonies in Japan. Viruses **4**(7), 1093-1103

Morgenthaler, O. (1934) Krankheitserregende und harmlose Artender Bienenmilbe *Acarapis*, zugleich ein Beitrag zum species-problem. Rev Suisse Zool. **41**, 429-446

Mossadegh, M.S. (1990) *In vitro* observations on ontogenesis of the mites, *Euvarroa sinhai* Delfinado and Baker (Acari: Varroidae), in drone brood cells of the honey bee, *Apis mellifera* L, J. Apic. Res. **29**, 230-232

Mossadegh, M.S. (1991) Geographical distribution, levels of infestation and population density of the mite *Euvarroa sinhai* Delfinado and Baker (Acarina: Mesostigmata) in *Apis florea* F colonies in Iran. Apidologie **22**, 127-134

Mossadegh, M.S., Bahreini, R. (1994) *Acarapis* mites of honey-bee, *Apis mellifera* in Iran, Exp. Appl. Acarol. **18**, 503-506

Naug, D. (2009) Nutritional stress due to habitat loss may explain recent honeybee colony collapses. Biol. Con. **142**, 2369-2372

Navajas, M., Anderson, D.L., de Guzman, L.I, Huang, Z.Y., Clement, J., Zhou, T., Le Conte, Y. (2010) New Asian types of *Varroa destructor*: a potential new threat for world apiculture. Apidologie **41**,181-193

National Bureau of Agricultural Commodity and Food Standards (2008) Diagnosis of American foulbrood in bee. National Thai Agricultural Standard TAS 10351-2007, Royal Gazette Vol.125 Special Section 3 D, 4 January B.E.2551. 16pp

Neumann, P., Elzen, P.J. (2004) The biology of the small hive beetle (*Aethina tumida*, Coleoptera: Nitidulidae): Gaps in our knowledge of an invasive species. Apidologie **35**, 229-247

Neumann, P., Carreck, N.L. (2010) Honey bee colony losses. J. Apic. Res. **49**, 1-6

1041 Noh, J. H., Reddy, K. E., Choe, S. E., Yoo, M. S., Doan, H. T. T. et al. (2013) Phylogenetic
1042 analysis of black queen cell virus genotypes in South Korea. Virus Genes **46**(2), 362-
1043 368
1044 Office International des Épizooties (OIE) (2004) World animal health 2004. Animal health
1045 status and disease control methods. Part 2. Tables. Office International des Épizooties,
1046 Paris. France.
1047 Oldroyd, B., Wongsiri, S. (2006) Asian honey bees: Biology, Conservation, and Human
1048 Interactions. Harvard University Press. London, England.
1049 Ono, M., Okada, I., Sasaki, M. (1987) Heat production by balling in the Japanese honeybee,
1050 *Apis cerana japonica* as a defensive behavior against the hornet, *Vespa simillima*
1051 *xanthoptera*. Experientia **43**, 1031-1032
1052 Otis, G.W. (1996) Distribution of recently recognized species of honey bees (Hymenoptera:
1053 Apidae; *Apis*). J. Kans. Entomol. Soc., supplement **69**, 311-333
1054 Otis, G.W., Kralj, J. (2001) Parasitic mites not present in North America, in: Webster, T.C.,
1055 and Delaplane, K.S. (Eds) Mites of the honey bee. Dadant, Hamilton, IL, pp. 251-272
1056 Oudemans, A.C. (1904) On a new genus and species of parasitic Acari, Notes Leyden Mus. **2**,
1057 216-222
1058 Pattamayutanon, P., Angeli, S., Thakeow, P., Abraham, J., Disayathanoowat, T.,
1059 Chantawannakul, P. (2015) Biomedical activity and related volatile compounds of
1060 Thai honeys from three different honeybee species. J. Food Sci. DOI: 10.1111/1750-
1061 3841.12993
1062 Pernal, S.F., Clay, H. (2013). Honey bee diseases and pests, 3rd Edition. Canadian
1063 Association of Professional Apiculturists, Beaverlodge AB, Canada 68 pp.
1064 Peng, Y.S., Fang, Y., Xu, S., Ge, L. (1987a) The resistance mechanism of the Asian
1065 honeybee, *Apis cerana* Fabr., to an ectoparasitic mite, *Varroa jacobsoni* Oudemans. J.
1066 Invertebr. Pathol. **49**, 54-60

1067 Peng, Y.S., Fang, Y., Xu, S., Ge, L., Nasr, M.E. (1987b) Response of foster Asian honeybee
1068 (*Apis cerana* Fabr.) colonies to the brood of European honeybee (*Apis mellifera* L.)
1069 infested with parasitic mite, *Varroa jacobsoni* Oudemans. J. Invertebr. Pathol. **49**,
1070 259-264
1071 Promnuan, Y., Kudo, T., Chantawannakul, P. (2009). Actinomycetes isolated from beehives
1072 in Thailand. World J. Microb. Biot. **25**(9), 1685-1689
1073 Promnuan, Y., Kudo, T., Ohkuma, M., Chantawannakul, P. (2011). *Actinomadura apis* sp.
1074 nov., isolated from a honey bee (*Apis mellifera*) hive, and the reclassification of
1075 *Actinomadura cremea* subsp. *rifamycini* Gauze et al. 1987 as *Actinomadura rifamycini*
1076 (Gauze et al.1987) sp. nov., comb. nov. Int. J. Syst. Evol. Microbiol. **61**(9), 2271-2277
1077 Ra, D.K., Jeong, C., Lee, J.H., Lee, Y.M., Kim, K.H., Han, T.H., Lee, S. M. (2012)
1078 Prevalence of honeybee diseases in Incheon area in 2011. Korean J. Vet. Serv. **35**,
1079 111-117
1080 Radloff S.E., Hepburn H.R., Fuchs S., Otis G.W., Hadisoesilo S., Hepburn C., Tan, K.
1081 (2005a) Multivariate morphometric analysis of the *Apis cerana* populations of oceanic
1082 Asia. Apidologie **36**, 475-492. DOI: 10.1051/apido:2005034
1083 Radloff S.E., Hepburn H.R., Hepburn C., Fuchs S., Otis G.W., et al. (2005b) Multivariate
1084 morphometric analysis of *Apis cerana* of southern mainland Asia. Apidologie **36**, 127-
1085 139. DOI: 10.1051/apido:2004077
1086 Radloff S.E., Hepburn C., Hepburn H.R., Fuchs S., Hadisoesilo S., Tan K., Engel, M.S.,
1087 Kuznetsov, V. (2010) Population structure and classification of *Apis cerana*. Apidologie
1088 **41**, 589-601. DOI: 10.1051/apido/2010008
1089 Raffique, M.K., Mahmood, R., Aslam, M., Sarwar, G. (2012) Control of *Tropilaelaps*
1090 *clareae* mite by using formic acid and thymol in honey bee *Apis mellifera* L. colonies
1091 Pakistan J. Zool. **44**, 1129-1135
1092 Rana, B.S., Rao, K.M., Chakravarty, S.K., Katna, S. (2012) Characterization of *Melisococcus*

plutonius causing European foulbrood disease in *Apis cerana* F. J. Apic. Res. **51**, 306-311

Rashad, S.E., Eweis, M.A., Nour, M.E. (1985) Studies on the infestation of honeybees (*Apis mellifera*) by *Acarapis woodi* in Egypt. Proc. 3rd. Intern. Conf. Apic. Trop. Climates, Nairobi. **1984**, 152-156

Reddy, K. E., Noh, J. H., Kim, Y.-H., Yoo, M. S., Doan, H. T. T. et al. (2013) Analysis of the nonstructural and structural polyprotein regions, and complete genome sequences of Israel acute paralysis viruses identified from honeybees (*Apis mellifera*) in Korea. Virology **444**(1–2), 211-217

Rennie, J. (1921) Isle of Wight disease in hive bees -acarine disease: the organism associated with the disease- *Tarsonemus woodi*. N. sp. Trans. R. Soc. Edinburgh **52**, 768-779

Rice, R. (2001) Nosema diseases in honeybees. Genetic variation and control RIRDC 1/46. Rural Industries Research and Development Corporation, Kingston, 36 pp.

Rinderer, T. E., Harris, J.W., Hunt, G., de Guzman, L.I. (2010) Breeding for resistance to *Varroa destructor* in North America. Apidologie **41**, 409-424

Rinderer, T.E., Oldroyd, B.P., Lekprayoon, C., Wongsiri, S., Thapa, R. (1994) Extended survival of the parasitic mite *Tropilaelaps clareae* on adult workers of *Apis mellifera* and *Apis dorsata*. J. Apic. Res. **33**, 171-174

Rinderer, T. E., Wongsiri, S., Kuang, B., Liu, J., Oldroyd, B., Sylvester, H. A., de Guzman, L.I. (1996) Comparative nest architecture of the dwarf honey bees. J. Apic. Res. **35**, 19-26

Ritter, W., Schneider-Ritter, U. (1988) Differences in biology and means of controlling *Varroa jacobsoni* and *Tropilaelalps clareae*, two novel parasitic mites of *Apis mellifera*, in: Needham, G.R., Page, R.E. Jr, Delfinado-Baker, M., and Bowan, C.E. (Eds) Africanized honeybees and bee mites. Halsted Press, New York, pp. 387-395

1118 Rosenkranz, P, Aumeier, P, Ziegelmann, B. (2010) Biology and control of *Varroa destructor*.
1119 J. Invertebr. Pathol. **103**, S96-S119
1120 Royce, L.A., Krantz, G.W., Ibay, L.A., Burgett, D.M. (1988) Some observations on the
1121 biology and behavior of *Acarapis woodi* and *Acarapis dorsalis* in Oregon, Needham,
1122 G.R., Page, R.E. Jr, Delfinado-Baker, and M., and Bowan, C.E. (Eds) Africanized
1123 honeybees and bee mites. Halsted Press. New York, pp. 98-505
1124 Ruttner, F. (1988) Biogeography and taxonomy of honey bees. Springer Verlag, Berlin. 284
1125 pp.
1126 Sakagami, S.F., Matsumura, T., Ito K. (1980) *Apis laboriosa* in Himalaya, the little known
1127 world's largest honey bee (Hymenoptera, Apidae). Insecta Matsumurana **19**, 47-78
1128 Sammataro, D. (2011) Global status of honey bee mites. In: Sammataro, D., Yoder, J.A.
1129 (eds.) Honey Bee Colony Health: Challenges and Sustainable Solutions, CRC Press,
1130 Boca Raton, USA. pp. 41-58
1131 Sanpa, S., Chantawannakul, P. (2009) Survey of six bee viruses using RT-PCR in Northern
1132 Thailand. J. Invertebr. Pathol. **100**, 116-119
1133 Sanpa, S., Popova, M., Bankova, V., Tunkasiri, T., Eitssayeam, S. Chantawannakul, P. (2015)
1134 Antibacterial compounds from propolis of *Tetragonula laeviceps* and *Tetrigona*
1135 *melanoleuca* (Hymenoptera: Apidae) from Thailand. PLoS ONE. **10**(5) e0126886
1136 Saraithong, P., Li, Y., Saenphet, K., Chen, Z., Chantawannakul, P. (2015) Bacterial
1137 community structure in *Apis florea* larvae analyzed by denaturing gradient gel
1138 electrophoresis and 16S rRNA gene sequencing. Insect Sci. **22**, 606–618, DOI:
1139 10.1111/1744-7917.12155
1140 Saraithong, P., Li, Y., Saenphet, K., Chen, Z., Chantawannakul, P. (In Press) Midgut bacterial
1141 communities in the giant Asian honeybee (*Apis dorsata*) across four developmental
1142 stages: A comparative stud. Insect Sci., DOI: 10.1111/1744-7917.12271
1143 Simone-Finstrom. M.D., Spivak, M. (2012) Increased Resin Collection after Parasite

1144 Challenge: A Case of Self-Medication in Honey Bees? PLoS ONE 7(3): e34601.
1145 doi:10.1371/journal.pone.0034601
1146 Simone, M., Evans, J.D., Spivak, M. (2009) Resin collection and social immunity in honey
1147 bees. Evolution 63: 3016-3022. DOI: 10.1111/j.1558-5646.2009.00772.x
1148 Singh, S. (1961) Appearance of American foulbrood disease in Indian honey bee (*Apis indica*
1149 Fabr.). Indian Bee J. **23** (7/9), 46-50
1150 Shah, F.A. Shah, T.A. (1988) Thai sacbrood disease of *Apis cerana*. Indian Bee J. **50**,110-
1151 112
1152 Shimanuki, H., Calderone, N.W., Know, D.A. (1994) Parasitic mite syndrome: the symptom.
1153 Am. Bee. J. **134**, 827-828
1154 Solignac, M., Cornuet, J., Vautrin, D., Le Conte, Y., Anderson, D., Evans, J., Cros-Arteil, S.,
1155 Navajas, M. (2005) The invasive Korean and Japanese types of *Varroa destructor*,
1156 ectoparasite mite of the Western honey bee (*Apis mellifera*), are two partially isolated
1157 clones. Proc. R. Soc. London B **272**, 411-419
1158 Stanley J., Sah K., Jain S. K., Bhatt J. C., Sushil S. N. (2015) Evaluation of pesticide toxicity
1159 at their field recommended doses to honeybees, *Apis cerana* and *A. mellifera* through
1160 laboratory, semi-field and field studies. Chemosphere **119**, 668–674
1161 Suwannapong, G., Yemor, T., Boonpakdee, C., Benbow, M.E. (2011) *Nosema ceranae*, a new
1162 parasite in Thai honeybees. J. Invertebr. Pathol.**106** (2), 236-241
1163 Takahashi J., Yoshida T., Takagi T., Akimoto S., Woo K.S., Deowanish, S., Hepburn, R.
1164 Nakamura, J., Matsuka, M. (2007) Geographic variation in the Japanese islands of
1165 *Apis cerana japonica* and in *A. cerana* populations bordering its geographic range.
1166 Apidologie **38**, 335-340. DOI 10.1051/apido:2007018
1167 Takamatsu, D., Morinishi, K., Arai, R., Sakamoto, A., Okura, M., Osaki, M (2014) Typing of

Melissococcus plutonius isolated from European and Japanese honey bees suggests spread of sequence types across borders and between different *Apis* species. Vet. Microbiol. **171**, 221-226

Tan, K., Hepburn, H.R., Radloff, S.E., Yu, Y., Liu, Y., Zhou, D., Neumann, P. (2005) Heat-balling wasps by honeybees. Naturwissenschaften **92**, 492-495

Tan, K., Hepburn, H.R., Radloff, S.E., Fuchs, S., Fan, X., Zhang, L., Yang, M. (2008) Multivariate morphometric analysis of the *Apis cerana* of China. Apidologie **39**, 343-353. DOI 10.1051/apido:2008014

Tan, K., Li, H., Yang, M.X., Hepburn, H.R., Radloff, S. E. (2010) Wasp hawking induces endothermic heat production in guard bees. J. Insect Sci. **10**, 1-6

Theantana, T., Chantawannakul, P. (2008) Protease and beta-N acetylglucosaminidase of honey bee chalkbrood pathogen *Ascosphaera apis*. J. Apic. Res. **47**(1), 68-76

Tingek, S., Koeniger, N., Koeniger, G. (1996) Description of a new cavity-dwelling species of *Apis* (*Apis nuluensis*) from Sabah, Borneo with notes on its occurrence and reproductive biology (Hymenoptera, Apoidea, Apini). Senckenbergiana Biol. **76**, 115–119

Triyasut, P., Mookhploy, W., Kimura, K., Yoshiyama, M., Khongphinitbunjong, K., Chantawannakul, P. (In Press) First detection of honey bee viruses in wax moth. Chiang Mai J. Sci.

Tutkun, E., Maden S., Inci, A., Yilmarz, B. (1993) General situation of chalkbrood disease in honey bees in Turkey. Turk. Entomol. Derg. **17**(2), 65-68

Van der Zee, R., Pisa, L., Andonov, S., Brodschneider, R., Charrière, J.-D. et al. (2012) Managed honey bee colony losses in Canada, China, Europe, Israel and Turkey, for the winters of 2008-9 and 2009-10. J. Apic. Res. **51** (1), 100-114

Wanjai, C., Sringarm, K., Santasup, C., Pak-Uthai, S., Chantawannakul, P. (2012)

Physicochemical and microbiological properties of longan, bitter bush, sunflower and litchi honeys produced by *Apis mellifera* in Northern Thailand. J. Apic. Res. **51**, 36-44

Warrit, N., Smith, D.R., Lekprayoon, C. (2006) Genetic subpopulations of *Varroa* mites and their *Apis cerana* hosts in Thailand. Apidologie **37**, 19-30

White, G.F. (1913) Sacbrood, a disease of bees. US Department of Agriculture, Bureau of Entomology, Circular No. 169

Whitaker, J., Szalanski, A.L., Kence M. (2011). Molecular detection of *Nosema ceranae* and *N. apis* from Turkish honey bees. Apidologie **42**, 174–180

Williams, G.R., Sampson, M.A., Shutler, D., Rogers, R.E.L. (2008) Does fumagillin control the recently detected invasive parasite *Nosema ceranae* in western honey bees (*Apis mellifera*)? J. Invertebr. Pathol. **99**, 342-344

Williams, G.R., Shutler, D., Little, C.M., Burgher-MacLellan, K.L., Rogers, R.E.L. (2011) The microsporidian *Nosema ceranae*, the antibiotic Fumagilin-B (R), and western honey bee (*Apis mellifera*) colony strength. Apidologie **42**, 15-22

Williams, G.R., Tarpy, D.R., Vanengelsdorp, D., Chauzat, M.P., Cox-Foster, D.L., Delaplane, K.S., Neumann, P., Pettis, J.S., Rogers, R.E.L., Shutler, D. (2010) Colony Collapse Disorder in context. Bioessays **32**, 845-846

Wongsiri, S., Tangkanasing, P. (1987) Mites, pests and beekeeping with *Apis cerana* and *Apis mellifera* in Thailand. Am. Bee J. **127**, 500-503

Wongsiri, S., Tangkanasing, P., Sylvester, H.A. (1989) The resistance behavior of *Apis cerana* against *Tropilaelaps clareae*. Proc. First Asia-Pacific Conf. of Enotmol. Chiang Mai, Thailand, 828-836

Wongsiri, S., Thapa, R., Chantawannakul, P., Chaiyawong, T., Thirakhupt, K., Meckvichai, W. (2005) Bee eating birds and honey bees predation in Thailand. Am. Bee. J. **145**(5), 419-422

1218 Woyke, J. (1984) Survival and prophylactic control of *Tropilaelaps clareae* infesting *Apis*
1219 *mellifera* colonies in Afghanistan. Apidologie **15**, 421-434
1220 Woyke, J. (1985) Further investigations into control of the parasite bee mite *Tropilaelaps*
1221 *clareae* without medication. J. Apic. Res. **24**, 250-254
1222 Woyke, J. (1987a) Infestation of honeybee (*Apis mellifera*) colonies by the parasitic mites
1223 *Varroa jacobsoni* and *Tropilaelaps clareae* in South Vietnam and results of chemical
1224 treatment. J. Apic. Res. **26**, 64-67
1225 Woyke, J. (1987b) Length of stay of the parasitic mite *Tropilaelaps clareae* outside sealed
1226 honeybee brood cells as basis for its effective control. J. Apic. Res. **26**, 104-109
1227 Woyke, J. (1987c) Length of successive stages in the development of the mite *Tropilaelaps*
1228 *clareae* in relation to honeybee brood age. J. Apic. Res. **26**, 110-114
1229 Wu, J., Li, J., Li, J.K. (2006) Major honey plants and their utilization in China. Am. Bee
1230 J. **2**, 153-157
1231 Yang, G.-H. (2005) Harm of introducing the western honeybee *Apis mellifera* L. to the
1232 Chinese honeybee *Apis cerana* F. and its ecological impact. Acta Entomol. Sin. **48**,
1233 401–406

1234 Yang, B., Peng, G., Li, T., Kadowaki, T. (2013) Molecular and phylogenetic characterization
1235 of honey bee viruses, Nosema microsporidia, protozoan parasites, and parasitic mites
1236 in China. Ecol. Evol. **3**(2), 298-311
1237 Yen, D,F., Chyn, L.C. (1971) Studies on a bacterial disease of honey bee in Taiwan. Plant
1238 Protection Bulletin **13**, 12-17

1239 Yoo, M.S., Yoon, B.S (2009) Incidence on honey bee disease in Korea 2009. Korean J.
1240 Apicul. **24**(4), 273-278

1241 Yoshiyama, M., Kimura, K. (2011) Distribution of *Nosema ceranae* in the European
1242 honeybee, *Apis mellifera* in Japan. J. Invertebr. Pathol. **106**, 263-267

1243 Zander, E. (1909) Tierische Parasiten als Krankenheitserreger bei der Biene. Münchener
1244 Bienenzeitung **31**, 196-204

1245 Zhang, X., He, S. Y., Evans, J. D., Pettis, J. S., Yin, G. F., Chen, Y. P. (2012). New evidence
1246 that deformed wing virus and black queen cell virus are multi-host pathogens. J
1247 Invertebr Pathol, **109**(1), 156-159

1248 Zhou, T., Feng, F., Dong, B. (2000) Study on the pathogen of European foulbrood in the
1249 Chinese honey bee (*Apis cerana cerana* F.) Acta Entomol. Sinica **43**, 104-108
1250 Zhou, T., Anderson, D., Huang, Z., S H., Yao, J., Tan, K., Zhang, Q. (2004) Identification of
1251 *Varroa* mites (Acari: Varroidae) infesting *Apis cerana* and *Apis mellifera* in China.
1252 Apidologie **35**, 645-654

1253

1254

1255

1256

1257

1258

1259

1260

1261

1262

1263

Figure legends

Figure 1 *Apis cerana* beekeeping in China A) Traditional hive (Hubei) B) Modern box (Chongqing)

Figure 2 Distribution map of *Varroa* spp. in Asia. A) *Varroa destructor*, B) *Varroa jacobsoni*, C) *Varroa rindereri*, D) *Varroa underwoodi*. Dark grey indicates Asian countries where the parasite has been detected in at least one honey bee species; light grey indicates Asian countries where the parasite has not been detected or no data (ND) are available.

Figure 3 Distribution map of *Tropilaelaps* spp. in Asia. A) *Tropilaelaps clareae*, B) *Tropilaelaps koenigerum*, C) *Tropilaelaps mercedesae, D*) *Tropilaelaps thaii*. Dark grey indicates Asian countries where the parasite has been detected in at least one honey bee species; light grey indicates Asian countries where the parasite has not been detected or no data (ND) are available.

Figure 4 Distribution map of *Euvarroa* spp. in Asia. A) *Eurvarroa sinhai*, B) *Euvarroa wongsirii*. Dark grey indicates Asian countries where the parasite has been detected in at least one honey bee species; light grey indicates Asian countries where the parasite has not been detected or no data (ND) are available.

Figure 5 Distribution map of fungal pathogens and diseases in Asia. A) *Nosema apis*, B) *Nosema ceranae*, C) Chalkbrood and D) Stonebrood. Dark grey indicates Asian countries where the parasite has been detected in at least one honey bee species; light

grey indicates Asian countries where the parasite has not been detected or no data (ND) are available.

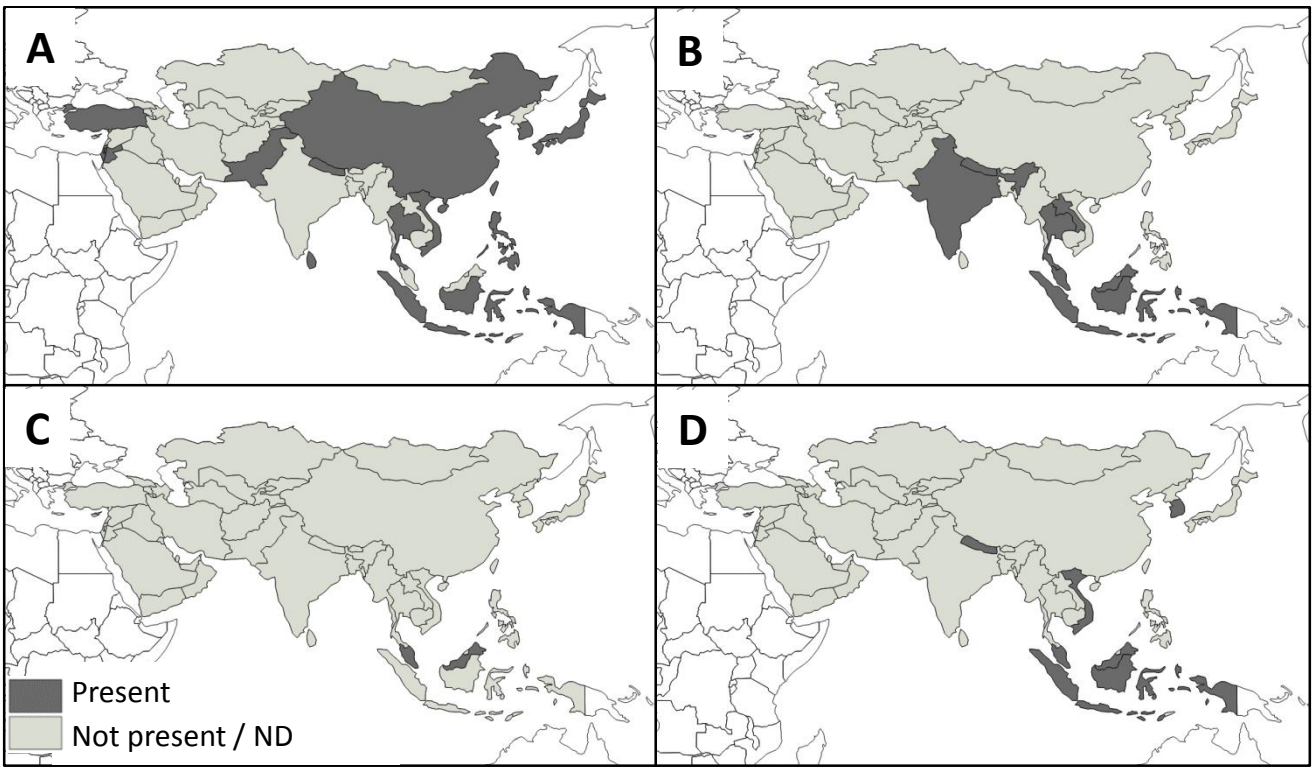
Figure 6 Distribution map of bacteria dieseses A) American foulbrood and B) European foulbrood in Asia. Dark grey indicates Asian countries where the parasite has been detected in at least one honey bee species; light grey indicates Asian countries where the parasite has not been detected or no data (ND) are available.

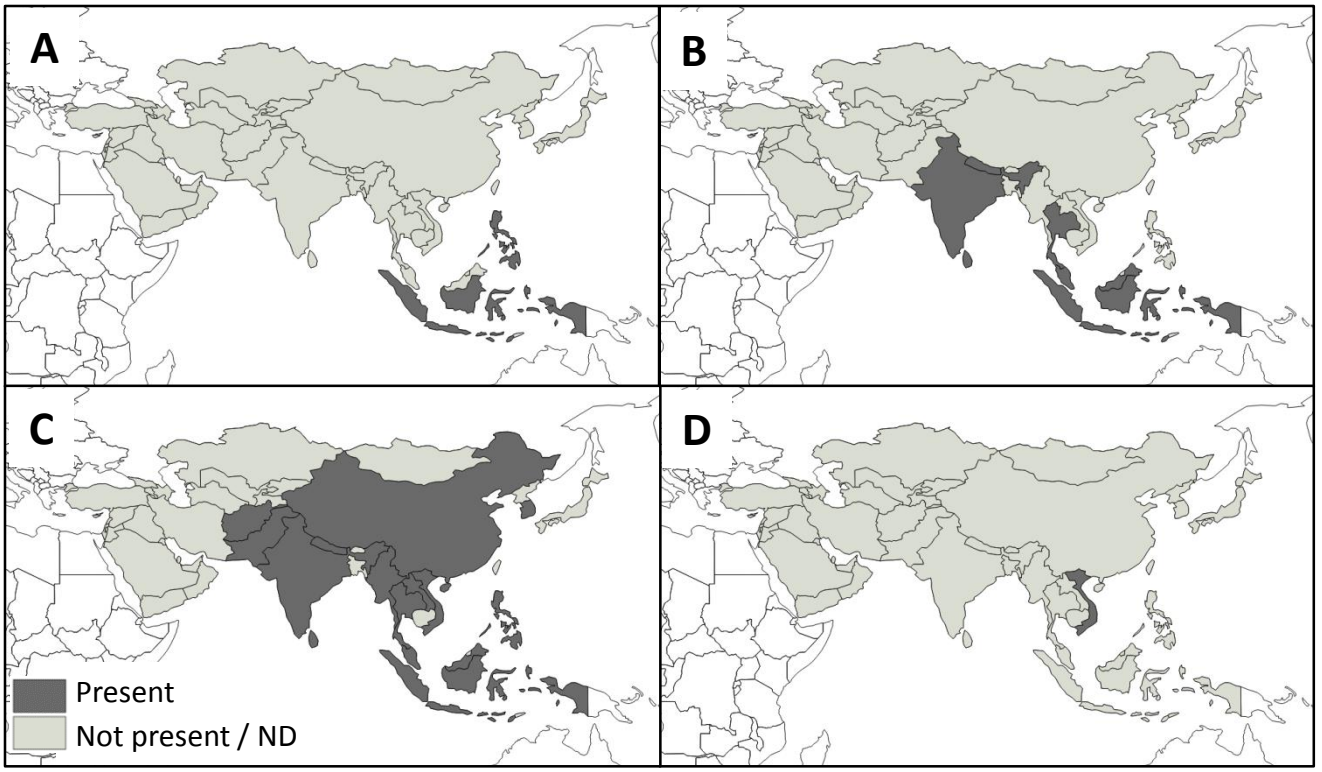
Table 1. Differences in body size for all parasitic mites of honey bees in Asia. Aa - *A. andreniformis*, Ac - *A. cerana*, Ad - *A. dorsata*, Adbi - *A. d. binghami*, Adbr - *A. d. briviligula*, Af - *A. florea*, Ak - *A. koschevnikovi*, Al - *A. laboriosa*, Am - *A. mellifera*, Ani - *A. nigrocincta*, Anu - *A. nuluensis*.

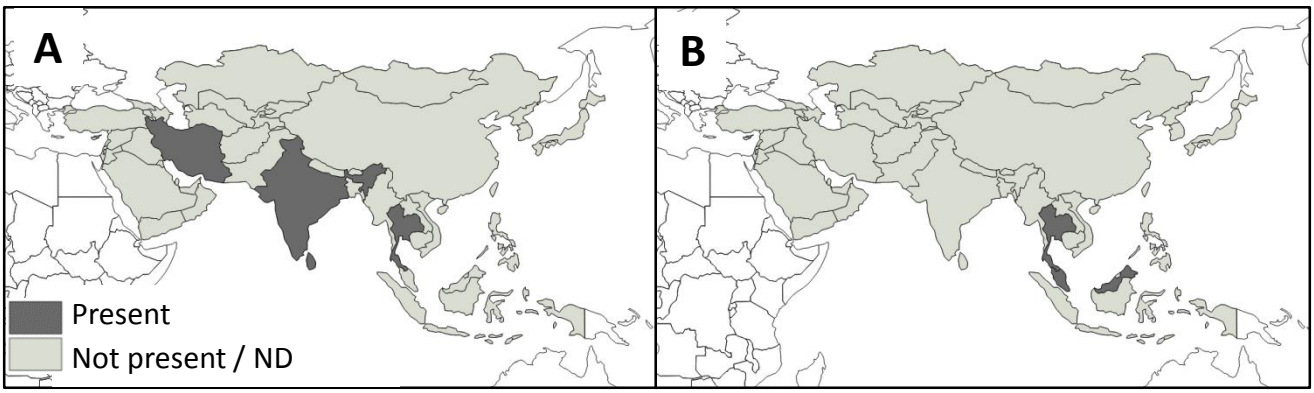
Mite Species	Bee Host	Length (um)	Width (um)	Reference
Family Varroidae				
Varroa jacobsoni	Ac	1,063-1077	1,507-1596	Anderson and Trueman 2000, de Guzman and Delfinado-Baker 1996
Varroa destructor	Am, Ac	1,167	1,709	Anderson and Trueman 2000
Varroa rindereri	Ak	1,180	1,698	de Guzman and Delfinado-Baker 1996
Varroa underwoodi	Ac, Ani, Anu, Am	690-820	1,050-1,360	Delfinado-Baker and Aggarwal 1987, Anderson et al. 1997, de Guzman and Rinderer 1999
Euvarroa sinhai	Af	1,040	1,000	Delfinado and Baker 1974
Euvarroa wongsirii	Aa	1,000	1,125	Lekprayoon and Tangkanasing 1991
Family Laelapidae				
Tropilaelaps clareae	Am, Adbr, Adbi,	882-976	485-528	Delfinado and Baker 1961, Anderson and Morgan 2007
Tropilaelaps mercedesae	Am	979	542	Anderson and Morgan 2007
Tropilaelaps koenigerum	Ad, Al	684-713	428-456	Delfinado-Baker and Baker 1982, Anderson and Morgan 2007
Tropilaelaps thaii	Al	890	492	Anderson and Morgan 2007
Family Tarsonemidae				
Acarapis woodi	Am	151	86	Eckert 1961
Acarapis dorsalis	Am	151	81	Eckert 1961
Acarapis externus	Am	170	105	Eckert 1961

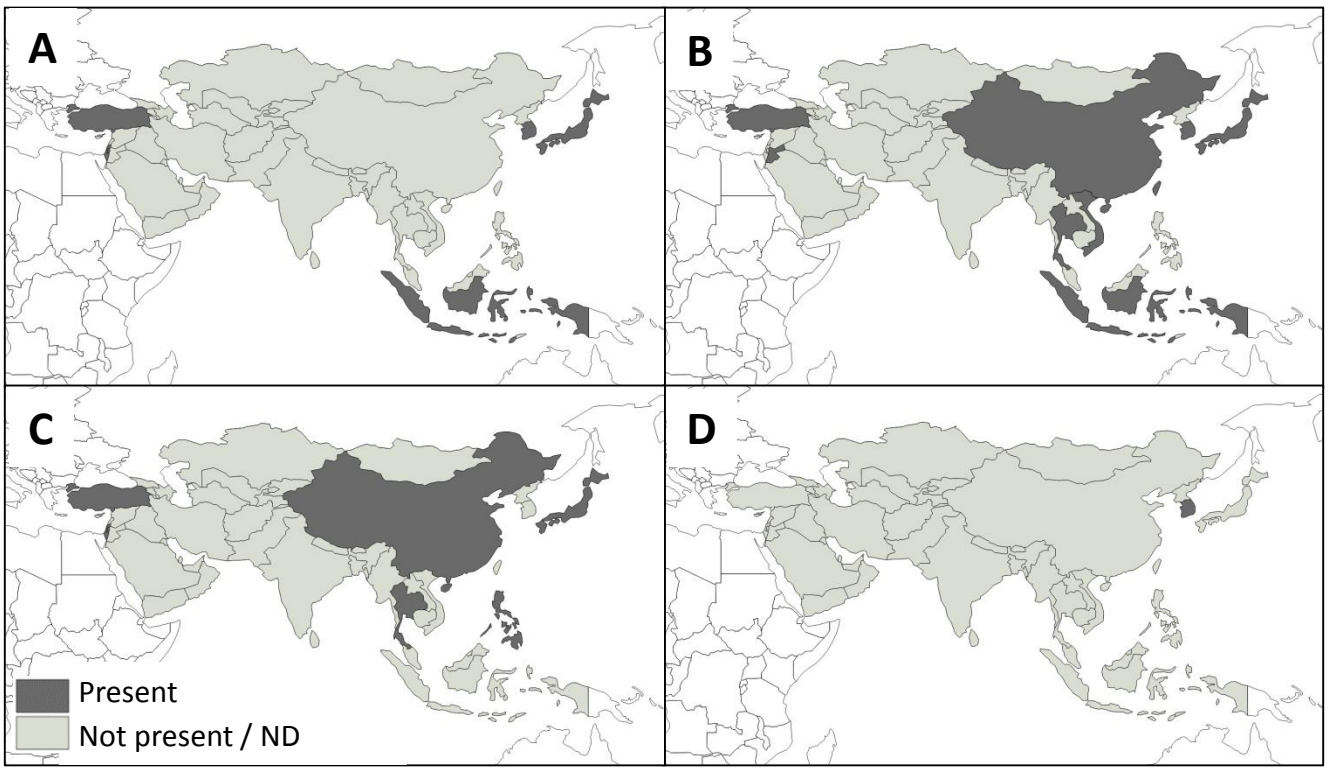
line figure

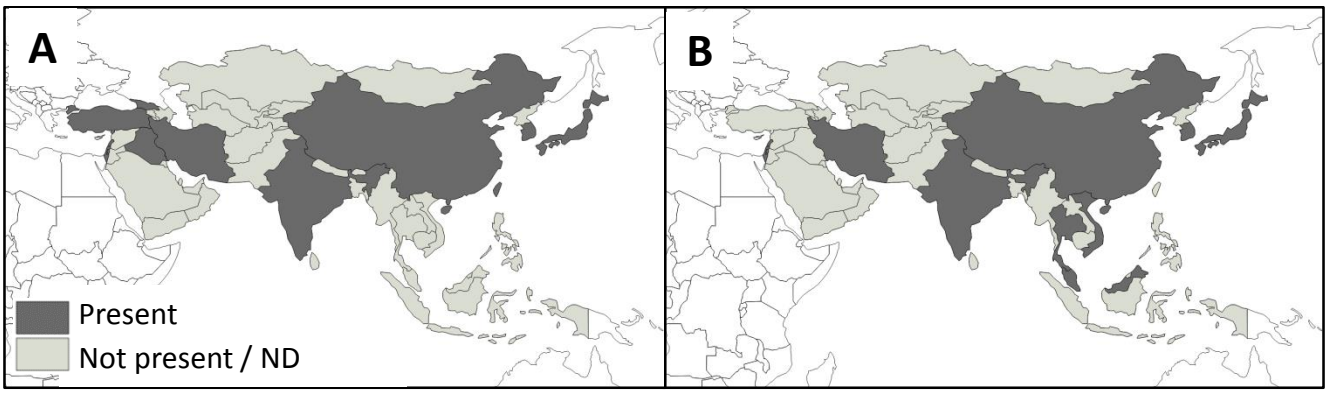
Click here to download line figure DistributionFigures.pptx




A
B
C
D
Present
Not present / ND


A
B
Present
Not present / ND


A
B
C
D
Present
Not present / ND


A
B
Present
Not present / ND

colour figure1A

Click here to download colour figure FIG1A.JPG

colour figure1B

Click here to download colour figure FIG1B.jpg